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Ship Navigation Simulation Study, Houston-Galveston Navigation Channels, Texas

Report 1
Houston Ship Channel, Bay Segment

by J. Christopher Hewlett

WES

Prepared for U.S. Army Engineer District, Galveston

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Report 1 of a series

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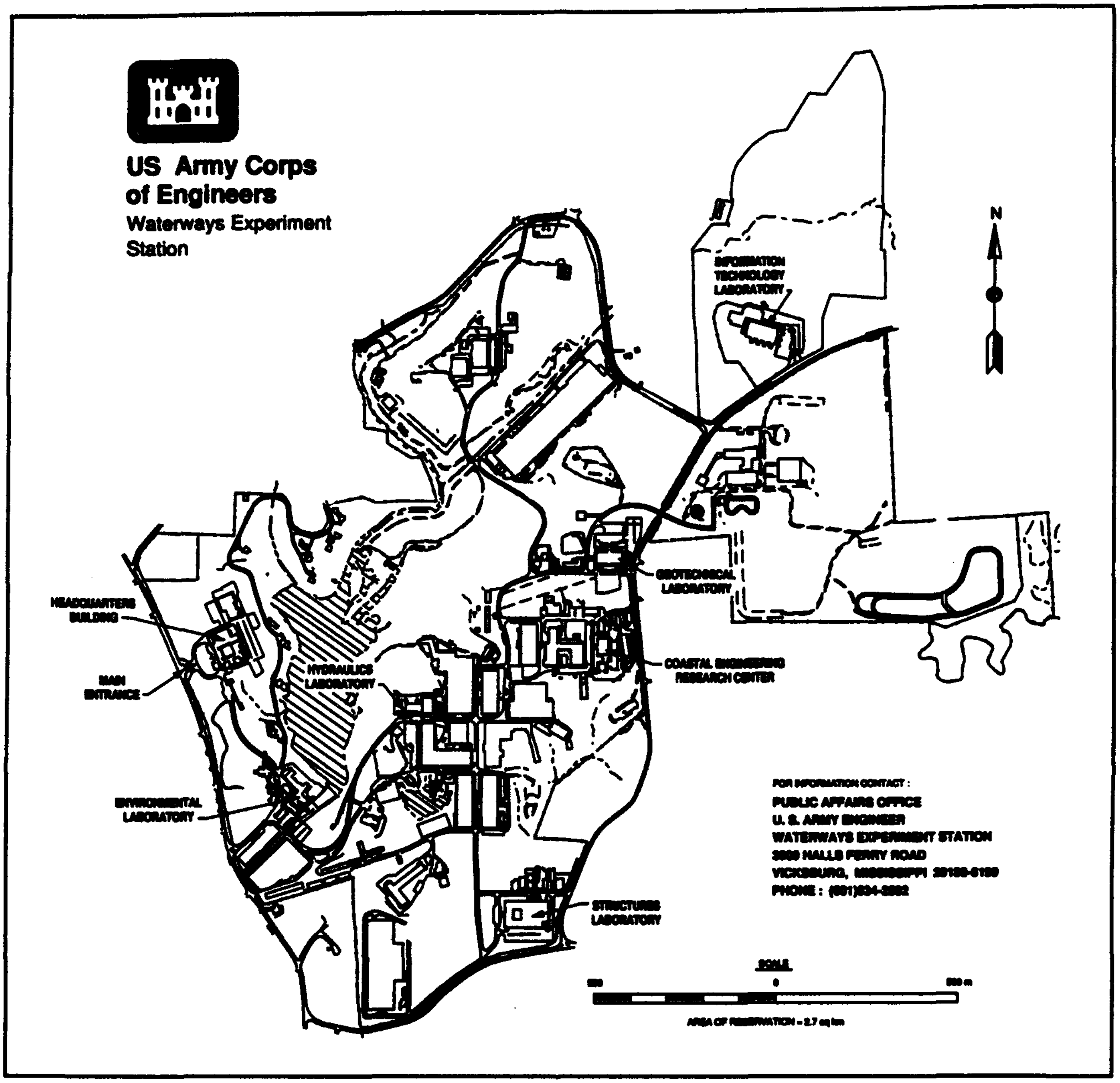

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Preface

This investigation was performed by the Hydraulics Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES) for the U.S. Army Engineer District, Galveston (SWG). The study was conducted with the WES research ship simulator during the period April 1990-June 1991. SWG provided survey data of the prototype area. Current modeling was conducted by the Estuarine Processes Branch, Estuaries Division, Hydraulics Laboratory. This is Report 1 of a series. Report 2 discusses the navigation study for the bayou segment of the Houston Ship Channel.

This investigation was conducted by Mr. J. Christopher Hewlett of the Navigation Branch, Waterways Division, Hydraulics Laboratory, under the general supervision of Messrs. Frank A. Herrmann, Jr., Director of the Hydraulics Laboratory; Richard A. Sager, Assistant Director of the Hydraulics Laboratory; M. B. Boyd, Chief of the Waterways Division; and Dr. Larry L. Daggett, Chief of the Navigation Branch. Ms. Donna Derrick and Mr. Keith Green, Civil Engineering Technicians, Navigation Branch, assisted in the study. This report was prepared by Mr. Hewlett.

Acknowledgement is made to Dr. Thomas Rennie and Mr. Al Meyer, Engineering Division, SWG, for cooperation and assistance at various times throughout the investigation. Special thanks go to the Houston Pilots Association for participating in the study.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots (international)	0.5144444	meters per second
miles (U.S. statute)	1.609347	kilometers
miles (U.S. nautical)	1.852	kilometers

1 Introduction

The Houston Ship Channel

The Houston-Galveston Navigation Channels are located along the Gulf of Mexico coast in eastern Texas. These channels include the Galveston Entrance Channel, Galveston Channel, Bolivar Roads, Texas City Channel, and the Houston Ship Channel (HSC), which branches off the Bolivar Roads Channel, traverses Galveston Bay, and ends in Houston. This report focuses only on the Galveston Bay segment of the HSC, shown on Figure 1. This section of channel comprises three gentle bends separated by long straight reaches. The HSC, which serves the Port of Houston, is one of the busiest channels in the country. As reported by Houston ship pilots, the number of ship movements recently has been approaching 1,000 per month. The channel is used by a wide variety of traffic including tankers, bulk carriers, car carriers, and containerships. Numerous refineries above Morgan's Point provide destinations for the tankers; bulk loading facilities also line the channel in the same area. Containerships call predominantly at container terminals at Morgan's Point and Bayport, which is accessed via a privately maintained side channel. In addition to heavy ship traffic, the HSC also handles a large amount of tow traffic into and out of the area. Pilots entering the channel aboard large ships must be prepared to meet a wide variety of traffic passing the opposite way. Also, ship pilots usually have to overtake and pass other slower moving vessels (predominantly tow traffic). All this traffic leads to very congested and critical conditions most of the time in the HSC.

Existing Conditions and Navigation Problems

In the existing condition, the bay segment of the HSC is 40 ft[1] deep below mean low tide (mlt) and 400 ft wide. The three bends in the study area (Figure 1) do not have bend wideners. Ships with beams in the neighborhood of 140 to 145 ft use the channel; however, meeting/passing of two such ships is closely monitored and controlled by pilots and is not allowed except under certain circumstances. On the other hand, smaller ships such as Panamax

[1] A table of factors for converting non-SI units of measurement to SI units is found on page vi.

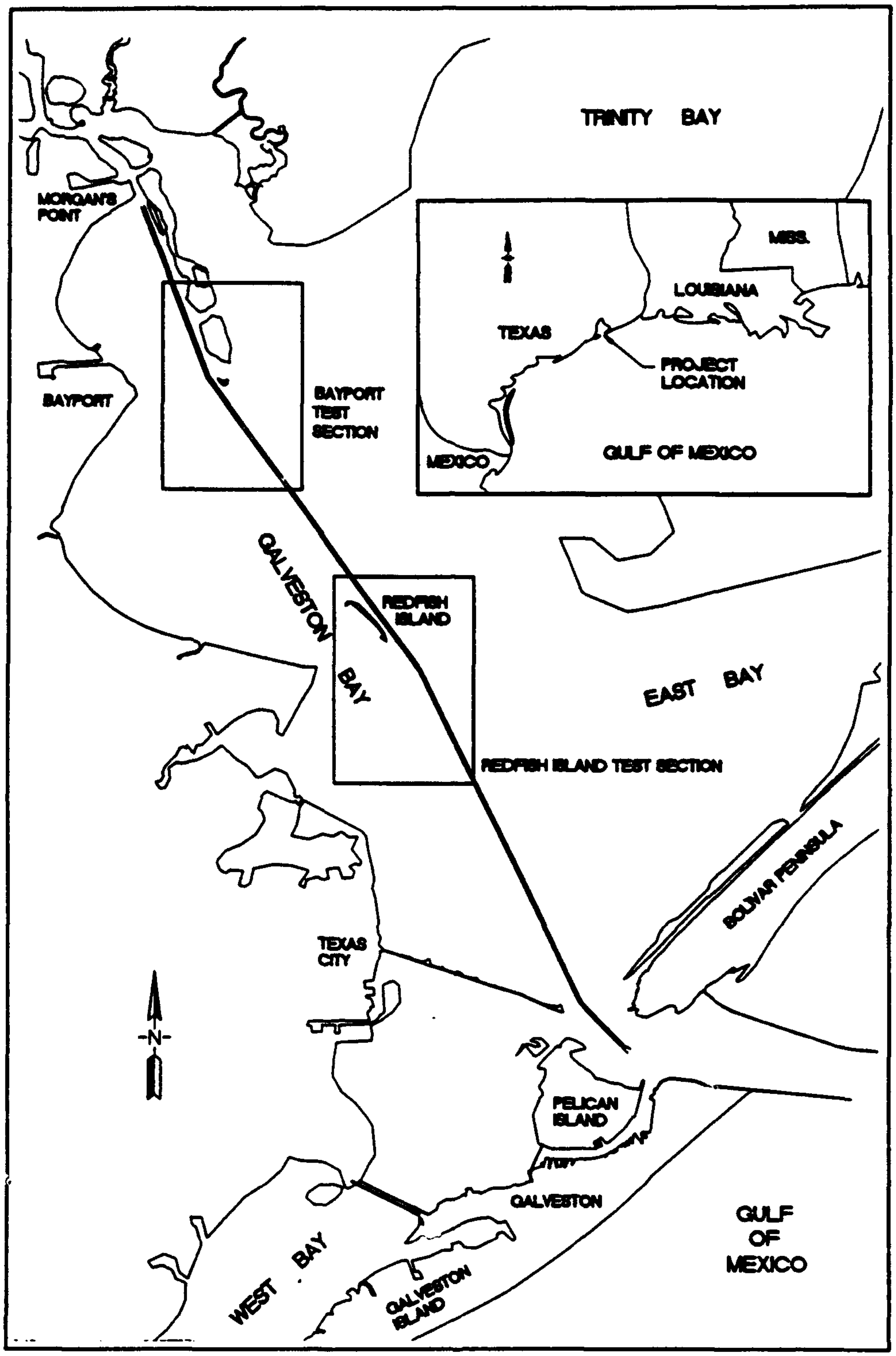

Figure 1. Location and vicinity map

types (106-ft beams) meet and pass each other on a regular basis. The meeting/passing maneuver is by far the most critical navigation problem in the study area. Winds and currents can cause problems at times, but their effects

on ship handling are insignificant when compared to the ship interaction during a meeting/passing maneuver.

Proposed Channel Improvements

The U.S. Army Engineer District (USAED), Galveston, has proposed a phased improvement plan for the HSC. In the Galveston Bay segment the Phase I channel is proposed to be 530 ft wide and 45 ft deep and the Phase II channel is to be 600 ft wide and 50 ft deep mean lower low water (mllw) (USAED, Galveston, 1987). The two proposed channels along with the existing channel composed the three channels tested in the navigation study at the U.S. Army Engineer Waterways Experiment Station (WES). All the test channels had the same alignment, with the exception of a slight 2-deg heading change for the proposed channels in the Morgan's Point to Bayport reach. The feasibility report (USAED, Galveston, 1987) indicates realignment of the proposed channels in the Redfish Island area; however, during navigation study planning the District redesigned the proposed channels to follow the existing channel alignment. Existing channel bottom and bank conditions (bank slope and overbank depth) were obtained from the most recent postdredging survey conducted by the District (May 1986). Bank conditions for the proposed channel were the same as for the existing channel except deeper.

Objective and Scope of Ship Navigation Study and Test Design

The navigation study was conducted using the WES Hydraulic Laboratory's ship simulator facility. The objective of the study was to test the adequacy of the Phase I and Phase II channels for two-way traffic using the design ships proposed by the District. Since the channel geometry of the long straight reaches of the HSC through Galveston Bay is fairly uniform, simulation tests were limited to two short sections. These sections were in the vicinity of two of the bends (boxed areas in Figure 1). One test reach was in the vicinity of the Bayport Channel just south of Morgans Point, known to Houston pilots as Five Mile bend. The other test reach straddled the channel bend in the vicinity of Redfish Island (Redfish Bend) near the center of Galveston Bay. Test conditions in the two sections were similar with the exception of stronger channel currents in the Redfish area. One simulator test of a proposed overtaking area (holding area) was conducted in the Bayport reach. The purpose of this test was to evaluate the capability of a large ship to steer into the holding area, slow down, and allow a smaller, faster ship to overtake it and pass.

Ship meeting and passing was the primary objective of most of the simulator tests. The simulations were designed to test various combinations of channel dimensions and ship draft and size (length and beam) to determine an optimum two-way traffic condition for the proposed channels. Both Phases I and II involved testing larger design ships than those used in the existing chan-

nel tests. The simulation model replicated the actual meeting/passing maneuver as closely as possible with interactive hydrodynamics affecting two ships moving in opposing directions. Modifications to the ship interaction modeling were checked with scale physical model tests. One of the ships had human pilot control while the other, the traffic ship, was controlled by a numerical line-following autopilot. Data input for the autopilot controlled when and by how much the traffic ship moved toward the side of the channel prior to meeting the piloted ship. The simulation tests were limited to fairly short runs with meeting/passing occurring after the bend in both of the test reaches. The channel/ship combinations tested for ship meeting and passing are shown in Table 1. Most of the tests were conducted with a 1-ft underkeel clearance; however, a few of the tests listed were with 2-ft underkeel clearance for a comparison of effects. The test ships will be discussed in more detail in Part II.

Table 1
Simulator Test Scenarios

Scenario Number	Piloted Ship Dimensions, ft	Traffic Ship Dimensions, ft	Test Channel	Test Reach
1	920x144x39 Inbound Tanker	775x106x39 Outbound Bulk Carrier	Existing	Bayport
2	775x106x39 Inbound Bulk Carrier	775x106x39 Outbound Bulk Carrier	Existing	Bayport
3	920x144x38 Inbound Tanker	775x106x38 Outbound Bulk Carrier	Existing	Bayport
4	775x106x39 Outbound Bulk Carrier	920x144x39 Inbound Tanker	Existing	Redfish
5	990x156x44 Inbound Tanker	971x140x44 Outbound Bulk Carrier	530-ft	Bayport
6	990x156x44 Inbound Tanker	990x156x25 Outbound Tanker	530-ft	Bayport
7	971x140x44 Outbound Bulk Carrier	990x156x44 Inbound Tanker	530-ft	Redfish
8	971x140x44 Outbound Bulk Carrier	990x156x25 Inbound Tanker	530-ft	Redfish
9	971x140x44 Inbound Bulk Carrier	971x140x44 Outbound Bulk Carrier	530-ft	Bayport
10	990x156x44 Inbound Tanker	775x106x44 Outbound Bulk Carrier	530-ft	Bayport
11	1013x173x49 Inbound Tanker	971x140x49 Outbound Bulk Carrier	600-ft	Bayport
12	1013x173x48 Inbound Tanker	971x140x48 Outbound Bulk Carrier	600-ft	Bayport
13	971x140x49 Outbound Bulk Carrier	1013x173x49 Inbound Tanker	600-ft	Redfish

2 Data Development

Description of Simulator

It is beyond the scope of this report to describe in detail the WES ship simulator;[1] however, a brief explanation will be made. The purpose of the WES ship simulator is to provide the factors necessary in a controlled computer environment to allow the inclusion of the man in the loop, i.e., local ship pilots, in the navigation channel design process. The simulator is operated in real-time by a pilot at a ship's wheel placed in front of a screen upon which a computer-generated visual scene is projected. The visual scene is updated as the hydrodynamic portion of the simulator program computes a new ship's position and heading resulting from manual input from the pilot (rudder, engine throttle, bow and stern thrusters, and tug commands) and external forces. The external force capability of the simulator includes effects of wind, waves, currents, banks, shallow water, ship/ship interaction, and tugboats. In addition to the visual scene, pilots are provided simulated radar and other navigation information such as water depth, relative ground and water speed of the vessel, magnitude of lateral vessel motions, relative wind speed and direction, and ship's heading.

Required Data

Data required for the simulation study included channel geometry, bottom topography, channel currents for proposed as well as existing conditions, numerical models of test ships, and visual data of the physical scene in the study area. Dredging survey sheets provided by the District were used for establishing channel alignment. Current data were obtained from a finite element numerical model of the Houston-Galveston navigation channels developed for navigation and salinity studies (Lin 1992). A reconnaissance trip was carried out to observe actual shipping operations in the study area. Video recordings and still photographs were taken during the reconnaissance transits

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[1] "Hydraulic Design of Deep Draft Navigation Channels," PROSPECT (Proponent Sponsored Engineer Corps Training) course notes, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 19-23 June 1989.

to aid in the generation of the simulated visual scene. Discussions with pilots were also held during this trip so that WES engineers could become more familiar with concerns and problems experienced during channel operations. A separate reconnaissance trip was carried out to record the position of two ships meeting and passing in the existing HSC. The positions of the ships were recorded using Global Positioning System (GPS) receivers, and the results served as a general verification of the simulation model of the meeting and passing operation. Figure 2 shows results of these prototype measurements. Both of the ships involved were in ballast condition and, therefore, are not directly comparable to the ships used in the simulation study. The strategy used by the pilots on the light loaded ships was different than with heavily loaded vessels. Because of the shallow draft, the pilots were less restricted in their movements and, prior to meeting, moved over earlier than they normally would with deeper ships. It is interesting to note that the larger ship actually gave way to the smaller ship and passed over the dredged channel slope (Figure 3).

Test File

The test file contains initial conditions (ship speed and heading, rudder angle, and engine setting) for the simulation and geographical coordinates for the channel alignment. The channel is defined in terms of cross sections located to coincide with changes in channel alignment and current direction and magnitude. The information used for the development of the HSC database was obtained from the District's project drawings. The Texas state plane coordinate grid, south-central zone, was also plotted on these drawings and was used for the simulator database coordinate system. Also included in the test file are the steepness and overbank depth (water depth at the top of the side slope) adjacent to the channel. These data are used by the computer to calculate bank suction forces on the test vessels. Specifications of other external forces such as wind and waves are also included in this file. Also, the definition of the autopilot track-line for both ships (piloted and traffic) and commands controlling the numerical autopilot are included in the test file.

For the HSC project the simulator channel cross sections were placed approximately 500 ft apart except where the bends occurred or where channel width changed, e.g., where the holding area opened up on one side of the channel. Since the test channels in the bay segment were fairly uniform, the simulator cross sections did not vary in spacing significantly. The simulator program handles the transition between cross sections on an interpolative basis.

Water depths for the simulator were based on authorized project depths. For the simulated existing channel, the water depth represented the existing condition taken from the most recent dredging survey furnished by the District. The simulator depth of the Phase I channel was a constant 45 ft, and for the Phase II channel it was 50 ft, also constant. Existing depths were maintained in the proposed channels when they were deeper than the proposed depths.

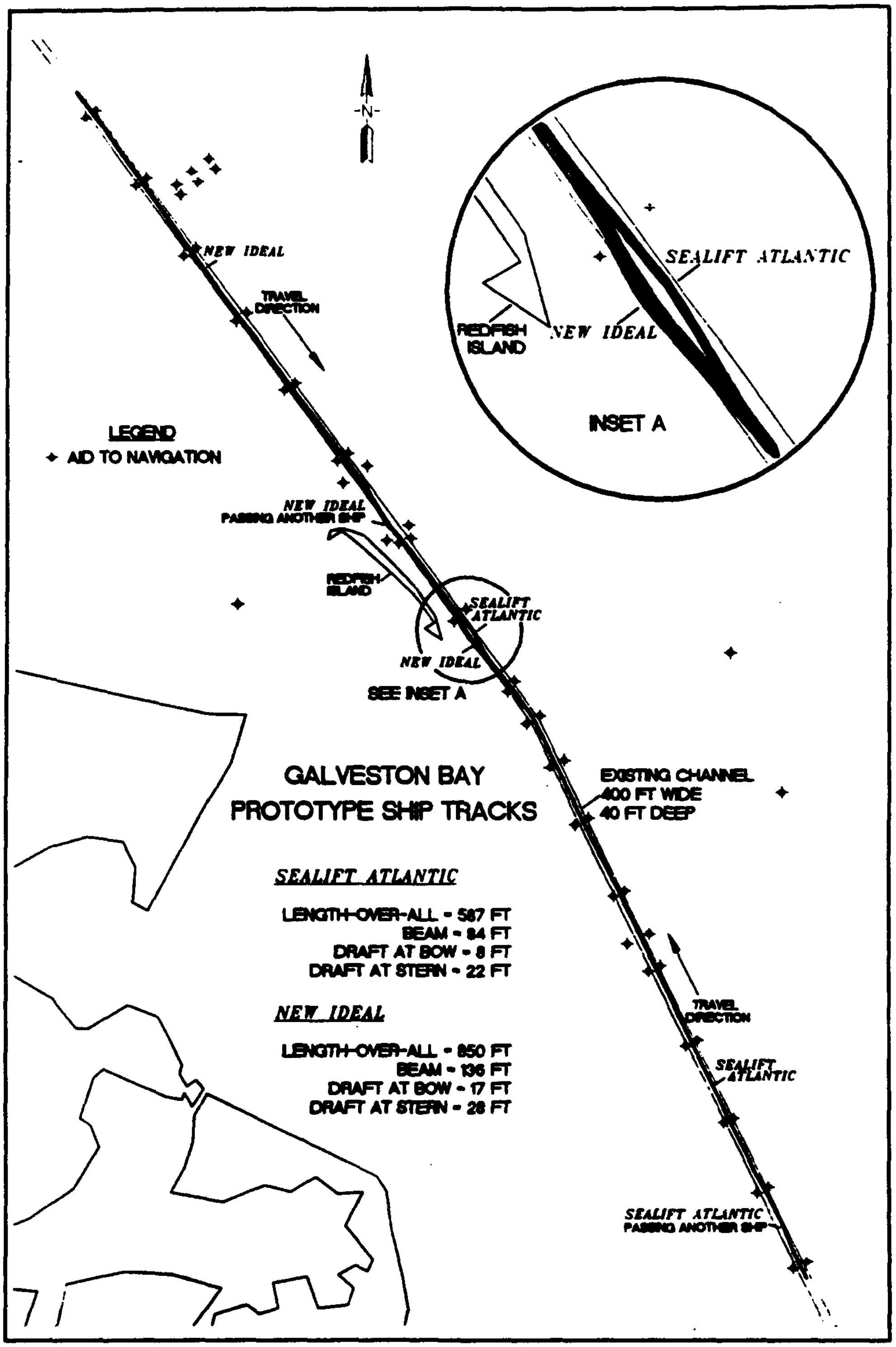

Figure 2. Actual ship tracks recorded in Galveston Bay

Also, bank slopes and overbank depths were obtained from the District dredging survey. These data are used in the calculation of ship hull bank forces. Briefly, bank forces occur when a ship travels close to a submerged bank

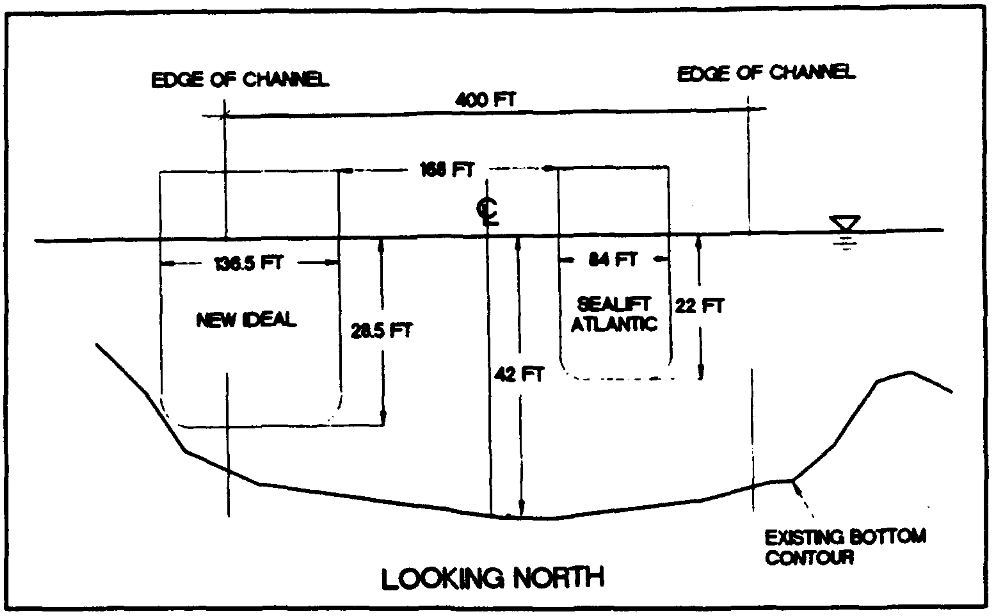

Figure 3. Hull clearance during meeting/passing maneuver

(also, wall or docked ship), and the resulting effect is characterized by a movement toward the bank and a bow-out rotation away from the bank. These bank effects become crucial in narrow channels such as the HSC and have a significant impact when two ships meet and pass each other in confined waterways.

Scene File

The scene database comprises several data files containing geometrical information enabling the graphics computer to generate the simulated scene of the study area. The computer hardware and software used for visual scene generation are separate from the main computer of the ship simulator. The main computer provides motion and orientation information to a stand-alone graphics computer for correct vessel positioning in the scene, which is then viewed by the pilot. Operators view the scene as if they are standing on the bridge of a ship looking toward the ship's bow in the foreground. View direction can be changed during simulation for the purpose of looking at objects outside of the relatively narrow straight-ahead view.

Aerial photographs, navigation charts, and dredging survey charts provided the basic data for generation of the visual scene. The simulation testing required low visual resolution beyond the immediate vicinity of the navigation channel. All land masses in the vicinity of the navigation channel were included in the scene. All aids to navigation in the vicinity of the study area were included. In addition to the man-made and topographical features in the vicinity, the visual scene included a perspective view of the bow of the ship

from the pilot's viewpoint. Visual databases for all design ships were developed at WES for use in the simulation.

Radar File

The radar file contains coordinates defining the border between land and water and significant man-made objects, such as docked ships and aids to navigation. These data are used by another graphics computer that connects the coordinates with straight lines and displays them on a terminal. The objects viewed comprise visual information that simulates shipboard radar. The main information sources for this database were the project drawings and dredging survey sheets supplied by the District.

Ship Files

The ship files contain characteristics and hydrodynamic coefficients for the test vessels. These data are the computer's definition of the ship. The coefficients govern the reaction of the ship to external forces, such as wind, current, waves, banks, underkeel clearance, and ship/ship interaction; and internal controls, such as rudder and engine revolution per minute (rpm) commands. The numerical ship models for the HSC simulations were developed by Tracor Hydronautics, Inc. of Laurel, MD (Ankudinov 1991a). The test ships were chosen based on the District's economic analysis of future shipping business and operations. Table 2 lists the particulars of the ships used in the simulations.

Current File

The current file contains current magnitude and direction and water depth for each of eight points across each of the cross sections defining the channel alignment. Current data for a ship simulation study are usually obtained from physical or numerical models. In this study, current data were available from a numerical model of Galveston Bay (Lin 1992). The numerical model for existing conditions was verified using prototype data, and the model bathymetry was modified for generation of currents for the two proposed conditions. Model data were generated using a spring tidal range for use in the simulation tests. In the Bayport vicinity, maximum flooding tidal currents were generally less than 1/3 knot. Maximum ebbing currents in the Redfish Island area were less than 1.5 knots. In both areas the currents were generally aligned with the channel and did not have a significant impact on navigation.

Table 2
Test Ship Characteristics

Ship Type	Length Overall ft	Beam ft	Draft ft	Test Channel
Bulk Carrier	775	106	39	Existing
			38	Existing
			44	530-ft
Tanker	920	144	39	Existing
			38	Existing
	990	156	44	530-ft
			25	530-ft
Bulk Carrier	971	140	44	530-ft
			49	600-ft
			48	600-ft
Tanker	1013	173	49	600-ft
			48	600-ft

3 Navigation Study

Validation

One of the most important milestones in the simulation process is the validation exercise for existing conditions. The purpose of validation is to use local pilot expertise to ensure that the simulation is as realistic as possible. While conducting validation tests, the pilots pay close attention to ship handling, external force effects, and objects in the visual scene and make comments and recommendations for improvement. Normally one or two pilots from the study area come to the simulator for validation; however, for the bay segment of the HSC study, additional pilots were required for check-out because of the complicated nature of the hydrodynamic phenomena being modeled.

For the HSC navigation study, the focus of validation was the simulator's modeling of the hydrodynamic interaction between ships during meeting and passing. Ship/ship interaction forces and moment on the simulator is calculated with a numerical model developed by Tracor Hydronautics, Inc. (Ankudinov 1988). This model generates vessel interaction forces and moments for the case of two ships meeting and passing on constant parallel (but opposite) courses. The calculation is based on inviscid potential flow and includes semiempirical corrections for additional factors that affect interaction, for example, hull appendages and shallow and confined channels.

Figure 4 shows a typical meeting/passing operation modeled by the simulator prior to validation exercises. The most notable characteristic is the strong bow-in moment after the bows pass each other, followed by strong bow-out moment from the time the vessels are abeam to when the sterns approach each other. In contrast, Figure 5 shows a typical meeting/passing operation as experienced by the Houston pilots. The most significant difference with Figure 4 is the lack of the strong bow-out moment when the ships are abeam (frame 4). As indicated in Figure 5, according to the pilots, once the bows have passed each other during the meeting, there is a constant tendency for the ship to rotate away from the closest (in this case starboard) bank and toward the other ship. A large amount of countering rudder is usually required to regain a straight course in the center of the channel. It should be noted that in Figure 5 the pilots were referring directly to ship *movement* rather

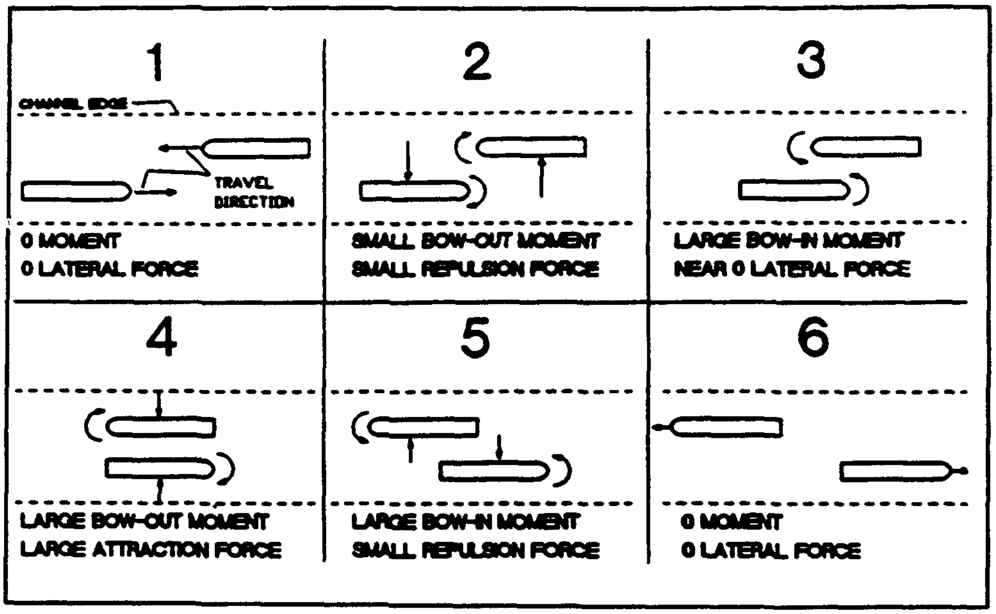

Figure 4. Numerical model of meeting passing

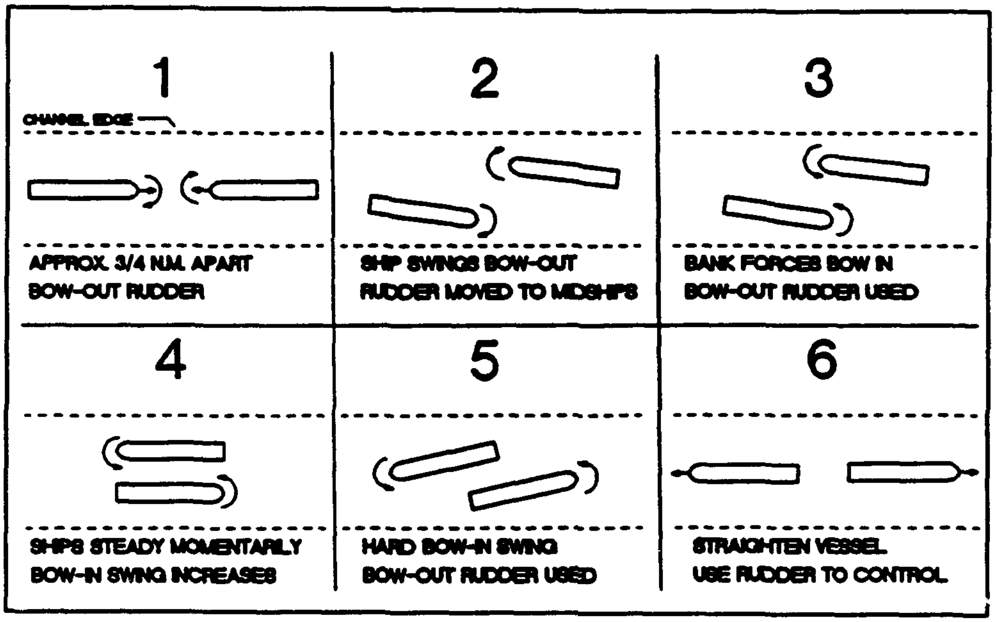

Figure 5. Meeting/passing based on pilot experience

than moment and forces as referred to in Figure 4. However, the two descriptions are essentially synonymous since ship movement closely paralleled the change of moment during the simulated operation. It became evident from validation testing that the existing simulator model of the meeting/passing operation needed modification to achieve an acceptable level of realism. The following differences are noted between the simulator modeling method and the actual meeting operation:

a. The simulator assumed the two ships were on constant parallel courses in their own half-channel lanes. In the actual operation the two ships travel down the center of the channel and move to the side prior to meeting after which they return to the channel center line. It was apparent through physical model tests that the orientation of ships just before meeting, had an important impact on the sequence of events in the meeting/passing maneuver.

b. In the simulation, only one of the ships was controlled by a human pilot while the other was controlled by a line-following numerical autopilot. The behavior of the autopiloted ship had a significant impact on the strategy of the human pilot in the simulation. The actual meeting/passing operation is very much a joint effort between two humans.

c. It was evident that the simulation model underestimated the effect of the extremely confined channel on the meeting operation. The most significant aspect of this appears to be the role that the very close, submerged banks play in the behavior of the ships. Pilot experience indicates that the bow-in moment imparted to the ship by the closest bank seems to cancel the bow-out moment (Figure 5, frame 4) measured in the restrained model tests, conducted in less confined water, on which the simulator model is based.

d. Another problem with confined water is the impact caused by low underkeel clearance. The simulator model limits ship underkeel clearance to no less than 5 percent of the ship draft. In short, the simulator model maintains water under the keel at all times. This is standard practice in simulation modeling at present because of the lack of reliable data on the maneuvering of vessels whose hulls are very close to the bottom. In the HSC, ships with less than 5 percent of channel depth under their keel frequently meet and pass in the channel. The simulator model is not sensitive to small differences in underkeel clearance when ship hulls are in close proximity to the channel bottom.

All of these factors indicate that the meeting/passing operation in the HSC is a very complicated, dynamic process that does not lend itself easily to simulation. Due to a combination of time and cost restraints and lack of reliable data, detailed model improvements for most of these factors listed based on rigorous systematic testing were not possible prior to pilot testing. Model adjustment focused on modification of the ship/ship interaction moment until a sequence of events similar to that shown in Figure 5 was produced during meeting and passing on the simulator. This required continuing the bow-in moment (Figure 4, frame 3) throughout the entire maneuver and increasing its magnitude, in effect, truncating any bow-out moment that the original computer model calculated. This modification forced the vessel to rotate toward the other ship throughout the meeting to simulate the ship behavior that the pilots have experienced. Also, some modifications were made in the way the model calculates bank effects by assigning higher weights to the forces

produced by the closer bank and reducing those from the opposite bank. These modifications were carried out with the help of a consultant (Ankudinov 1991b) and additional validation pilots. The following section describes the physic.: tests used for validation of the simulator model for the purpose of design of the HSC.

Comparison of Simulation with Physical Model Tests

As part of the navigation study, a 1:100-scale physical model of a generic section of the bay segment of the existing HSC was constructed at WES. Its primary purpose was to provide physical data for verification of the simulator ship/ship interaction modeling after making the modifications discussed in the previous section. Some of the necessary details concerning the scale model are discussed in the following paragraphs related to simulator validation.

Radio-controlled scaled ships were used in the physical model to replicate actual meeting and passing operations in the HSC. The tests were free-running tests with an overhead camera tracking system that recorded ship position during operation. The model was a straight reach that represented a typical Galveston Bay section of the HSC. Numerous tests were conducted with different setups and strategies using WES personnel and Houston pilots to obtain a qualitative understanding of the hydrodynamic processes of the meeting and passing maneuvers. Generally, the professional pilots who conducted these tests were pleased with the level of accuracy demonstrated in the scale model maneuvers. The modifications performed on the simulator numerical model were partly based on knowledge gained through observation of these scale model tests.

Because of the combination of hydrodynamic and human factors involved in meeting and passing maneuvers, a basis of comparison between simulator and scale model results was difficult to develop. For the scale model, replication is a problem, while on the simulator, the tests can be replicated with the use of a numerical autopilot. It was decided that the preferred method of comparison was to remove, to the extent possible, the human influence in the critical portion of the tests and compare only the hydrodynamic behavior of the ships. For the comparison tests on the simulator, both ships were placed in their respective half-channel lanes on parallel (but opposite) headings. The autopilot kept the ships on a straight course until just prior to the bows meeting, at which time the autopilot rudder was returned to midships and the test was completed without any further control. In the physical model tests, the setup was the same except the ship had human control (via telemetry) until just prior to the meeting when, again, the ship was aligned parallel to the channel and steadied. The rudder was then moved to midships, and the test was allowed to continue without additional human input. For these validation tests, ship sizes on the simulator were matched as closely as possible to those in the physical model. The following tabulation lists these ship dimensions:

Ship	Length Overall ft	Beam, ft	Draft, ft
Physical model			
1	805	90	36
2	840	126	36
Simulation Model			
1	810	106	36
2	840	138	36

Figures 6 and 7 show comparisons of physical model tests with simulator results for 6.5 and 9.5 knots, respectively. The shaded regions indicate variability ranges for physical model ship position (bow and stern), speed, and heading. These plots result from five separate runs for the 6.5-knot case and four runs for the 9.5-knot case. Human control during the first half of each of the physical model tests resulted in much of the variability. The single lines show simulator results for similar conditions.

For the 6.5-knot case (Figure 6), the paths from the two models are similar in general appearance. The primary difference is the way in which the submerged banks at the channel edge affected the behavior of the ships. In the physical model, the depth at the top of the channel edge slope was 10 ft; therefore, the ships were restricted from going out of the channel after the meeting occurred. Instead, the ships sheered off the banks back into the channel. The same process took place in the simulator results, but not before the ships drifted outside the 400-ft channel edge. This is a result of the 5 percent underkeel clearance restriction, which was discussed earlier, and the lack of a model of the physical restraint by the bank of the passage of the ship through the bank. Ship speed from the two models generally compares favorably. However, the speed of the physical models appeared to increase slightly when the ships first met, while the simulator results exhibited a slight dip in speed when the ship bows met. Ship heading indicates the occurrence of a process similar to that for ship position with the simulator ships maintaining a heading toward the bank for a longer period of time while the physical models sheer away. For the 9.5-knot case, basically the same patterns are indicated (Figure 7). The paths of the physical model ships deviate less from the channel center line than is evident in the 6.5-knot case. This is most likely a result of higher longitudinal momentum carrying the ship forward on a straighter course in the 9.5-knot case. On the contrary, the simulator ships seem to deviate the same amount as for the lower speed, but the bank sheer afterward is stronger.

Existing simulation models have limitations when predicting the hydrodynamic behavior of ships either very close to the bottom (or banks) or when the hulls are actually moving through fluid mud or sand. It is, however, indicated by the foregoing comparison that the simulator modeling method, adjusted as described in the previous section, will yield a conservative estimate of the width of channel required for meeting and passing operations in the HSC.

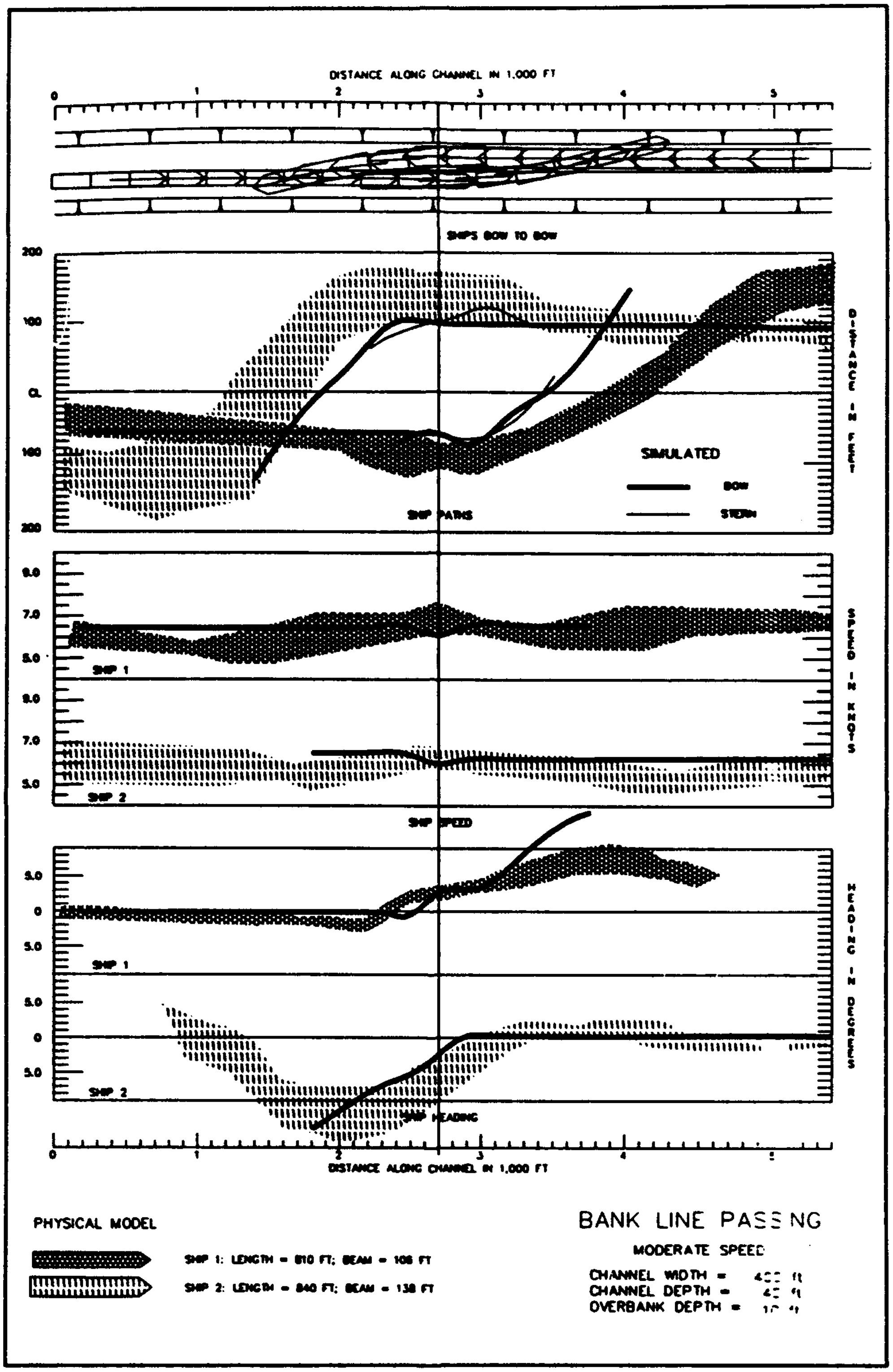

Figure 6. Comparison of physical model tests and simulator, 6.5 knots

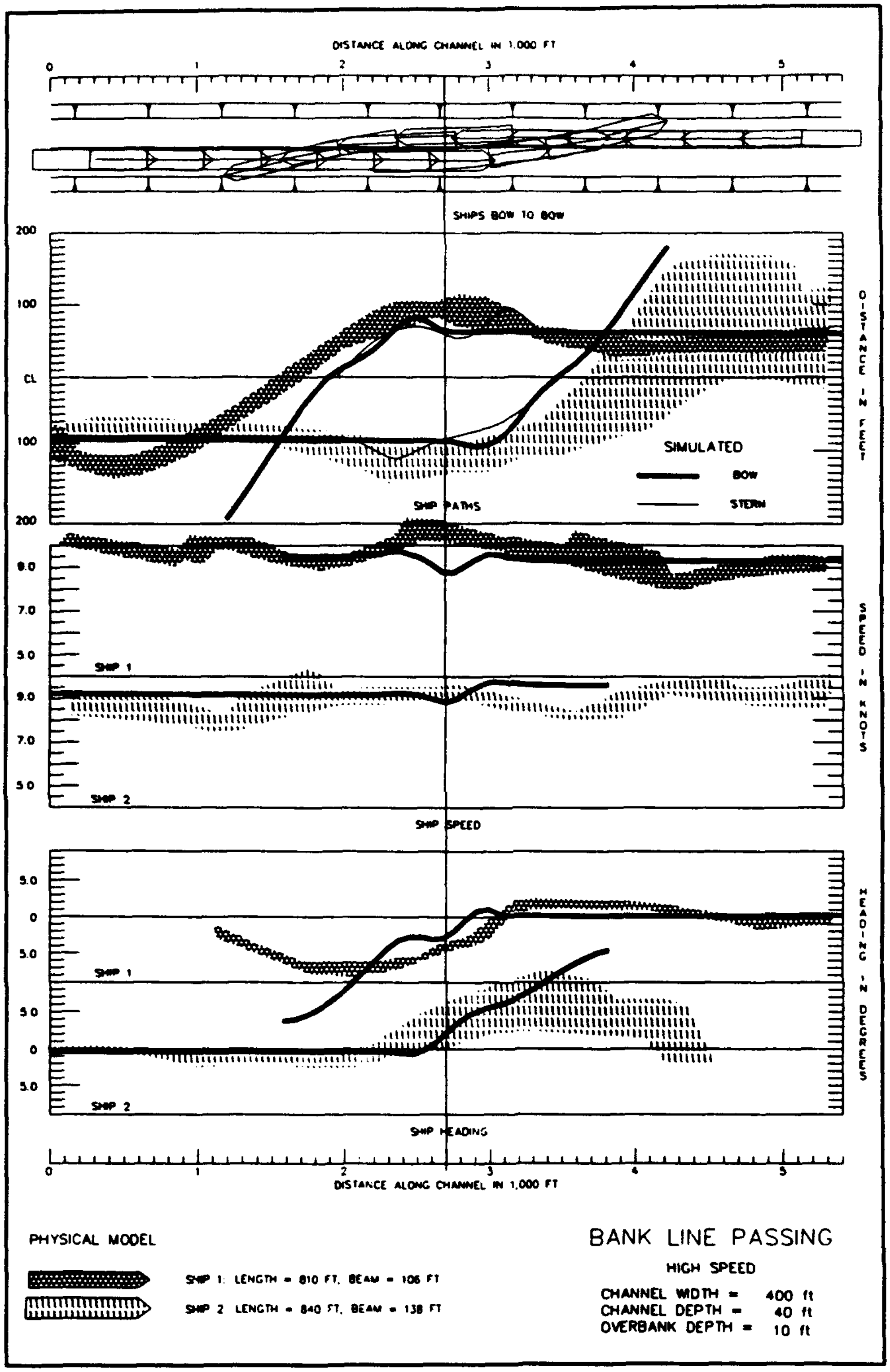

Figure 7. Comparison of physical model tests and simulator, 9.5 knots

4 Study Results

Simulation Runs

A total of seven professional pilots (pilots F, G, H, I, J, K, and L) from the Houston Pilots Association conducted simulator tests for the bay segment of the HSC. Table 3 shows the organization of plotted simulator results. Each of the track plots shows clearances recorded for the particular pilot run. The *minimum* clearance (shown as an inset on the plate) at ship meeting occurred when the two ships were abeam of one another and took into account the orientation of the ships in the channel. Other information is also included on the track plots such as approximate speed for both ships and the minimum port channel edge clearance for the piloted ship after meeting the traffic ship (recovery clearance). Each track plot has another plot associated with it showing the variation of selected control measures for the piloted ship, i.e., propeller rotation rate (rpm), speed, and rudder angle. The recorded control measures were averaged for each 250-ft segment traveled by the ship and then plotted against distance along track. Clearance measurements constitute the most efficient means of comparison of simulator results from the different test channels. Tables 4-8 show clearances as scenario averages (all pilots) and weighted mean averages for each of the test channels. The weighting was done according to the number of runs for each scenario. All negative clearances denoted on the individual track plots were assigned a value of 0.0 for calculation of averages. In all the tests, only one run resulted in a collision during meeting and passing (Plate 49). This run occurred in the 530-ft channel, and the resulting clearance values were not included in the calculations for Tables 4-8.

Plates 1-34 show the result of the runs conducted in the existing 400-ft by 40-ft channel. Scenarios 1, 3, and 4 with the 920x144x38 tanker and the 775x106x38 Panamax bulk carrier were not considered safe by the pilots. They had limited experience handling these ships in two-way traffic and had difficulty with the meeting/passing maneuver. Loaded ships of dimensions similar to the tanker do transit the channel regularly, but the pilots try to avoid meeting and passing other ships with them unless they have no choice. Scenario 2 (two 775x106x38 Panamax bulk carriers) was considered a more normal meeting operation.

Table 3
Scenario-Plate Number Cross Reference

Scenario[1]	Track Plot	RPM, Speed, and Rudder Angle
1	1,3,7,11,15	2,4,8,12,16
2	27,29,31,33	28,30,32,34
3	5,9,13,17	6,10,14,18
4	19,21,23,25	20,22,24,26
5	35,37	36,38
6	39,41,43,45,47,49	40,42,44,46,48,50
7	61,63,65,67,69,71 73,75,77	62,64,66,68,70,72 74,76,78
8	79,81,83	80,82,84
9	51,53,55	52,54,56
10	57,59	58,60
11	85,89,93,97	86,90,94,98
12	87,91,95,99	88,92,96,100
13	101,103,105,107 109,111,113	102,104,106,108 110,112,114

[1] See Table 1 for description of scenario.

The control measures plots for the existing channel generally show that a large amount of ship rudder was used in the existing channel. In nearly all of the runs in the Bayport vicinity, hard-over rudder was used to control the ship during meeting/passing. The pilots said this was normal practice, especially with deep-draft vessels. For the runs in the Redfish vicinity, the autopilot had difficulty controlling the larger tanker and it drifted too far toward the edge of the channel. In response to this, the human pilot kept his ship closer to the channel center line prior to meeting the traffic ship. This resulted in less interaction with the bank, requiring less rudder for ship control.

For the 530-ft channel (Plates 35-84), much the same pattern is seen regarding rudder activity during the tests. Most of the pilots had to use hard-over rudder to control the larger ships tested in the Bayport vicinity. Again, the results in the Redfish area indicate that less rudder was used because of the difficulty with autopilot control of the traffic ship. This same pattern is also evident in the 600-ft channel results (Plates 85-114).

For the existing channel, the clearances recorded in Tables 4-8 cannot be considered indicative of a safe channel. There were a number of very small clearances between the piloted ship and the bank (Table 4) and between the two passing ships (Table 5). The average minimum clearances between the piloted ship and the bank and between the ships were 44 ft and 63 ft,

Table 4
Average Clearances for all Runs in Each Test Condition, Piloted Ship, Minimum Starboard Edge Clearance During Meeting

Channel	Piloted Ship	Traffic Ship	Number of Runs	Average, ft	Minimum Clearance, ft	Maximum Clearance, ft
Existing Channel	920x144x39	775x106x39	5	41	13	70
	775x106x39	920x144x39	4	70	54	100
	775x106x39	775x106x39	4	37	7	68
	920x144x38	775x106x38	4	30	14	49
						Weighted Mean Average = 44 ft
530-ft Channel	990x156x44	971x141x44	2	70	61	79
	990x156x44	990x156x25	5	85	50	133
	971x140x44	990x156x44	9	74	39	134
	971x140x44	990x156x25	3	123	80	158
						Weighted Mean Average = 84 ft
530-ft Channel (restricted beam)	971x140x44	971x140x44	3	65	41	91
	990x156x44	775x106x44	2	59	52	66
						Weighted Mean Average = 62 ft
600-ft Channel	1013x173x49	971x140x49	4	87	63	114
	971x140x49	1013x173x49	7	115	72	155
	1013x173x48	971x140x48	4	74	40	91
						Weighted Mean Average = 96 ft

Note: All negative clearances are assigned a value of 0.0 for averaging.

Table 5
Average Clearances for all Runs in Each Test Condition, Minimum Clearance Between Ships During Meeting

Channel	Piloted Ship	Traffic Ship	Number of Runs	Average, ft	Minimum Clearance, ft	Maximum Clearance, ft
Existing Channel	920x144x39	775x106x39	5	68	42	96
	775x106x39	920x144x39	4	61	34	82
	775x106x39	775x106x39	4	46	10	70
	920x144x38	775x106x38	4	77	65	90
						Weighted Mean Average = 63 ft
530-ft Channel	990x156x44	971x140x44	2	90	81	100
	990x156x44	990x156x25	5	44	29	56
	971x140x44	990x156x44	9	71	33	124
	971x140x44	990x156x25	3	94	79	111
						Weighted Mean Average = 69 ft
530-ft Channel (restricted beam)	971x140x44	971x140x44	3	78	56	107
	990x156x44	775x106x44	2	70	68	72
						Weighted Mean Average = 74 ft
600-ft Channel	1013x173x49	971x140x49	4	94	68	117
	971x140x49	1013x173x49	7	114	58	171
	1013x173x48	971x140x48	4	102	96	112
						Weighted Mean Average = 105 ft

Note: All negative clearances are assigned a value of 0.0 for averaging.

Table 6
Average Clearances for all Runs in Each Test Condition, Piloted Ship, Minimum Port Channel Edge Clearance After Meeting

Channel	Piloted Ship	Traffic Ship	Number of Runs	Average, ft	Minimum Clearance, ft	Maximum Clearance, ft
Existing Channel	920x144x39	775x106x39	5	24	0	61
	775x106x39	920x144x39	4	128	107	149
	775x106x39	775x106x39	4	35	0	71
	920x144x38	775x106x38	4	18	0	34
						Weighted Mean Average = 49 ft
530-ft Channel	990x156x44	971x140x44	2	142	111	174
	990x156x44	990x156x25	5	99	0	167
	971x140x44	990x156x44	9	190	89	261
	971x140x44	990x156x25	3	189	178	200
						Weighted Mean Average = 160 ft
530-ft Channel (restricted beam)	971x140x44	971x140x44	3	129	0	239
	990x156x44	775x106x44	2	52	0	105
						Weighted Mean Average = 98 ft
600-ft Channel	1013x173x49	971x140x49	4	157	109	180
	971x140x49	1013x173x49	7	225	92	307
	1013x173x48	971x140x48	4	152	102	256
						Weighted Mean Average = 187 ft

Note: All negative clearances are assigned a value of 0.0 for averaging.

Table 7
Average Clearances for all Runs in Each Test Condition, Traffic Ship, Minimum Starboard Edge Clearance During Meeting

Channel	Piloted Ship	Traffic Ship	Number of Runs	Average, ft	Minimum Clearance, ft	Maximum Clearance, ft
Existing Channel	920x144x39	775x106x39	5	18	7	31
	775x106x39	920x144x39	4	0	0	0
	775x106x39	775x106x39	4	46	20	65
	920x144x38	775x106x38	4	20	11	27
						Weighted Mean Average = 20 ft
530-ft Channel	990x156x44	971x140x44	2	30	25	36
	990x156x44	990x156x25	5	82	60	101
	971x140x44	990x156x44	9	20	0	67
	971x140x44	990x156x25	3	33	50	55
						Weighted Mean Average = 22 ft
530-ft Channel (restricted beam)	971x140x44	971x140x44	3	52	50	54
	990x156x44	775x106x44	2	67	66	68
						Weighted Mean Average = 58 ft
600-ft Channel	1013x173x49	971x140x49	4	33	24	44
	971x140x49	1013x173x49	7	8	0	34
	1013x173x48	971x140x48	4	49	19	74
			Weighted Mean Average = 25 ft			

Note: All negative clearances are assigned a value of 0.0 for averaging.

Table 8
Average Total Clearances for all Runs in Each Test Condition

Channel	Piloted Ship	Traffic Ship	Number of Runs	Average Minimum Clearance, ft			
				Ship to Bank			
				Piloted Ship	Traffic Ship	Between Ships	Total Clearance
Existing Channel	920x144x39	775x106x39	5	41	18	68	127
	775x106x39	920x144x39	4	70	0	61	131
	775x106x39	775x106x39	4	37	46	46	129
	920x144x38	775x106x38	4	30	20	77	127
						Minimum	127
530-ft Channel	990x156x44	971x140x44	2	70	30	90	190
	990x156x44	990x156x25	5	85	82	44	211
	971x140x44	990x156x44	9	74	20	71	165
	971x140x44	990x156x25	3	123	33	94	250
						Minimum	165
530-ft Channel (restricted beam)	971x140x44	971x140x44	3	65	52	78	195
	990x156x44	775x106x44	2	59	67	70	196
						Minimum	195
600-ft Channel	1013x173x49	971x140x49	4	87	33	94	214
	971x140x49	1013x173x49	7	115	8	114	237
	1013x173x48	971x140x48	4	74	49	102	225
						Minimum	214

Note: All negative clearances are assigned a value of 0.0 for averaging.

respectively. The average total clearance (Table 8) is between 127 ft and 131 ft. This is a very small total clearance value.

Table 6 shows average values of the recovery clearance for the piloted ship. This clearance is a measure of the pilot's ability to control the ship after meeting the traffic ship. For the existing channel in the Bayport vicinity, control of the piloted ship following the meeting operation was very difficult. The weighted mean average clearance is less than 50 ft for these tests. The results in Table 8 show an increase in this recovery clearance in both the proposed channels compared to the existing case.

The pilots had two different strategies for the meeting maneuver: (a) slow the engine to half-ahead prior to meeting and go to full-ahead when the meeting occurred, and (b) keep the engine at full-ahead the whole time. Results indicate a possible dependency for the recovery clearance on strategy (a) because of a decrease in the average clearance when the piloted ship was traveling slower than the traffic ship at meeting. (The autopilot for the traffic ship maintained a full-ahead strategy in passing.) Calculations show that when strategy (a) was used in the existing channel, the average recovery clearance was 20 ft. When the piloted ship was at full-ahead, strategy (b), the average increased to 65 ft, still a small clearance. In the 530-ft channel the same pattern resulted with the corresponding values of 98 ft and 186 ft, respectively, for strategies (a) and (b). In the 600-ft channel, only one run was conducted in which the piloted ship moved slower than the traffic ship. As in the other cases, the recovery clearance for this run was 92 ft, the lowest recorded in the 600-ft channel, and less than half of the 194-ft average of all the rest of the 600-ft channel runs. This suggests that the slower ship in a meeting situation will be affected more than the other and in order to optimize ship control and safety both pilots should try to follow the same strategy and especially maintain similar speeds.

All measures of clearance show improvement in meeting/passing situations for both the 530- and 600-ft channels compared to the existing condition. The 530-ft channel provides some improvement and the 600-ft channel provides even more. However, in the 530-ft channel, the meeting/passing ship combinations (156-ft and 140-ft beams) proved to be too large. The minimum total clearance (Table 8) was 165 ft. The design guidance for two-way navigation channels in EM 1110-2-1613 (Headquarters, U.S. Army Corps of Engineers, 1983) calls for a 60-ft bank/ship clearance for both ships and 80 ft between ships for a total clearance of 200 ft. In order to bring the 530-ft channel to this standard, the channel width would require an increase of 35 ft. To help determine what combination of ships could meet and pass in the 530-ft channel, tests were conducted (pilots K and L) using ships whose combined beams totaled less than 280 ft. This value was used because it was approximately 35 ft less than the largest combined beam tested originally (156 ft and 156 ft), and there are a number of ships with beams of about 140 ft used in lightering operations in the HSC. Ship combinations of 140-ft/140-ft and 156-ft/106-ft beams were tested. Plates 51-60 show the results for these particular tests. Clearance values are shown for the restricted beam tests for

the 530-ft channel in Tables 4-8. In two of these tests the pilot had difficulty after ship meeting had occurred and drifted beyond the left channel edge; however, both of these cases were first runs, and the difficulty was probably because of unfamiliarity with the scenario. The most significant result is that the total clearance (Table 8) during meeting for the two test conditions was very close to 200 ft, indicating an adequate two-way passage.

The 600-ft channel tests resulted in average total minimum clearances of at least 214 ft (Table 8). Although some small clearances between the traffic ship and the bank (Table 7) resulted from poor control of the largest traffic ship (1013x140x49), most of the clearances are considered adequate. The one case that resulted in a grounding of the traffic ship had minimum clearance between the ships of 171 ft and between the piloted ship and the bank of 91 ft. Another case resulted in a minimum clearance between the ships of 58 ft and 123 ft between the piloted ship and the bank. If the piloted ship had moved over toward the bank more, the resulting forces on the traffic ship would have allowed the autopilot to control it better. Considering the other two test conditions for the 600-ft channel, the average minimum clearances are adequate and no groundings occurred.

Comparison of results in Tables 4-8 from tests with 1-ft and 2-ft underkeel clearances indicates insignificant differences in channel edge and ship/ship clearances. These tests did not account for the effects of squat, the potential of striking the bottom, and the resulting reduction of headway (which could affect traffic congestion).

Plate 115 shows one pilot run conducted in the 530-ft channel with a proposed overtaking area (holding area) in place. The holding area tested was 4,000 ft long with a total width of 830 ft. The loaded tanker (990x156x44) and the bulk carrier (775x106x39) were moving in the same direction with the smaller ship overtaking and passing the larger ship as it slowed down in the holding area. The autopilot on the overtaking ship was replaced by human control for this one run. Engine speed and rudder of the overtaking ship were controlled via computer keyboard instructions from a WES engineer who could see the position of the ship on the simulator radar. The most significant result of this test is the track-line of the large ship as it tried to slow down in the holding area. The relatively short length provided (approximately four ship lengths) forced the ship to reduce to a speed at which the pilot had difficulty controlling the vessel. In addition to this simulation, a few overtaking maneuvers were performed in the HSC physical model for general observation. It was evident from these tests that the overtaking ship actually pushes the other vessel to the side and drags it along the channel during the maneuver, causing a critical loss of control in the overtaken ship. The simulator test did not model this phenomenon; and, therefore, the test results give only an indication of the amount of time involved in the overtaking and a general sense of the level of ship handling difficulty. According to the pilots' comments after the simulator run, the holding area should have a length of 2 miles (approximately 12,000 ft or 12 ship lengths) and a channel width of 1,000 ft in order to allow enough maneuvering room for such large vessels.

Concerns

Evidence has been presented indicating that the simulation results in the bay segment of the HSC yielded conservative predictions of the behavior of the design ships in the proposed channels. However, the following discussion points out concerns to be kept in mind when interpreting the simulation results. These points define areas needing improvement for future simulations involving similar hydrodynamic processes.

The simulation could have been enhanced greatly by providing pilot control for the traffic ship. Meeting and passing situations are a joint effort between two pilots; therefore, if one ship does not react as an actual piloted ship would, the entire maneuver does not develop normally. Although the same modeling approach was used successfully in a Baltimore Harbor study, the extremely narrow channels and small underkeel clearances in the HSC resulted in very large dynamic forces that were not as successfully controlled by the autopilot. In some instances during the simulation tests, the autopilot allowed the traffic ship to break too far to the side of the channel in preparation for the meeting. The real pilot on the other ship reacted to this as he normally would by not moving over as far to the other side of the channel, creating an unusual meeting/passing maneuver in which the loaded traffic ship drifted well out of the channel.

During the tests conducted by pilots F, G, H, and I, questionnaires were completed after each run. The pilots were asked to rate the difficulty of the run and the realism of simulation on a scale of 0 to 10, with 0 corresponding to very easy and very unreal, respectively. Comparatively these pilots on average rated both of the proposed channels slightly easier than the existing channel. Average realism ratings were in the 3-5 range with the pilots rating the proposed channel simulations slightly less realistic than the existing channel. Throughout the test program the pilots were concerned that the numerical simulation was not modeling the behavior of the ships correctly. The pilots did not believe the larger ships would handle as easily in the proposed channels as the simulator indicated, even in the one-way situation. Even though they have little experience in these situations, the pilots believe that the ships will be rather unstable and difficult to control. This could be a result of the very small underkeel clearances used in the simulations, which existing numerical simulators may not model well. No data are available for these conditions, and the existing state of the art is to extrapolate the ship behavior changes for larger underkeel clearances to those for small depth to draft ratios. Furthermore, the effects of a moving bottom, i.e., mud or silt, on ship handling are not known. These are factors that require extensive study and research in order to enhance existing simulation models.

5 Recommendations

The following recommendations are made for the Galveston Bay section of the Houston Ship Channel.

a. Based on the simulation results, the proposed channel width of 600 ft for the fully deepened (50 ft) project is recommended.

b. If the intermediate channel project (45 ft) is to have a channel width of 530 ft, it is recommended that meeting/passing situations be limited to ships whose combined beams total less than 280 ft (53 percent of channel width). This criterion may result in operational restrictions being employed, e.g., holding other large ship traffic so that the channel is temporarily one-way or with restricted ship sizes traveling in the opposite direction of the large ship. These restrictions will most likely cause delays that may have to be accounted for in any economic analysis of channel improvements. If such operational procedures cannot be used, then it is recommended that the intermediate channel be widened by at least 35 ft.

c. It is not recommended that the overtaking area be constructed as tested in the simulation unless the overtaken ship can be slowed to a speed that allows tug control before the overtaking begins. If such is the case, the tugs would have to hold the ship in position throughout the overtaking maneuver and could cause traffic interference and delays. This operational procedure would probably require additional width depending on the size of the tugs used.

d. The tests were conducted without bend wideners and no passing in the bends. Based on these test results, it is recommended that no bend wideners are needed.

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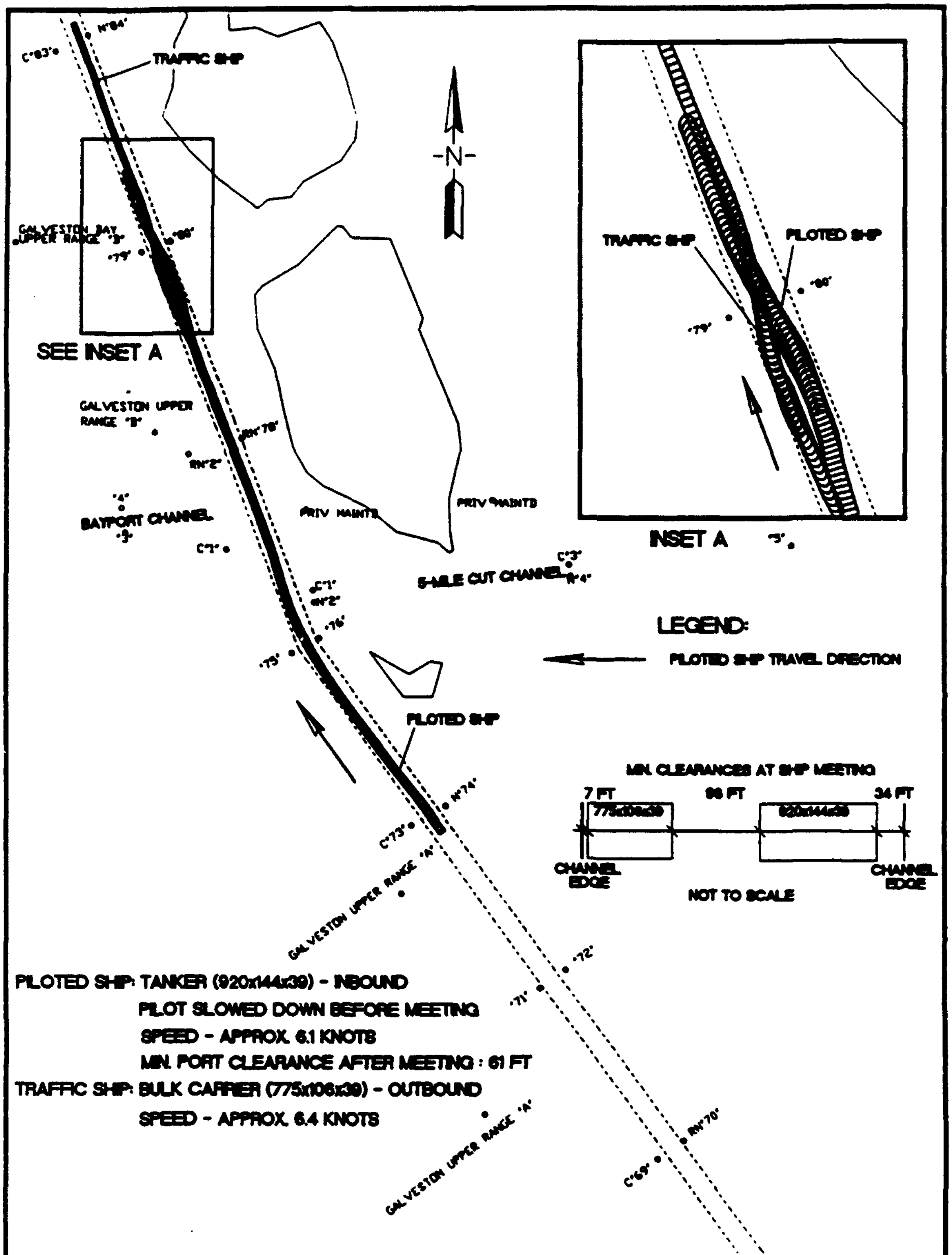
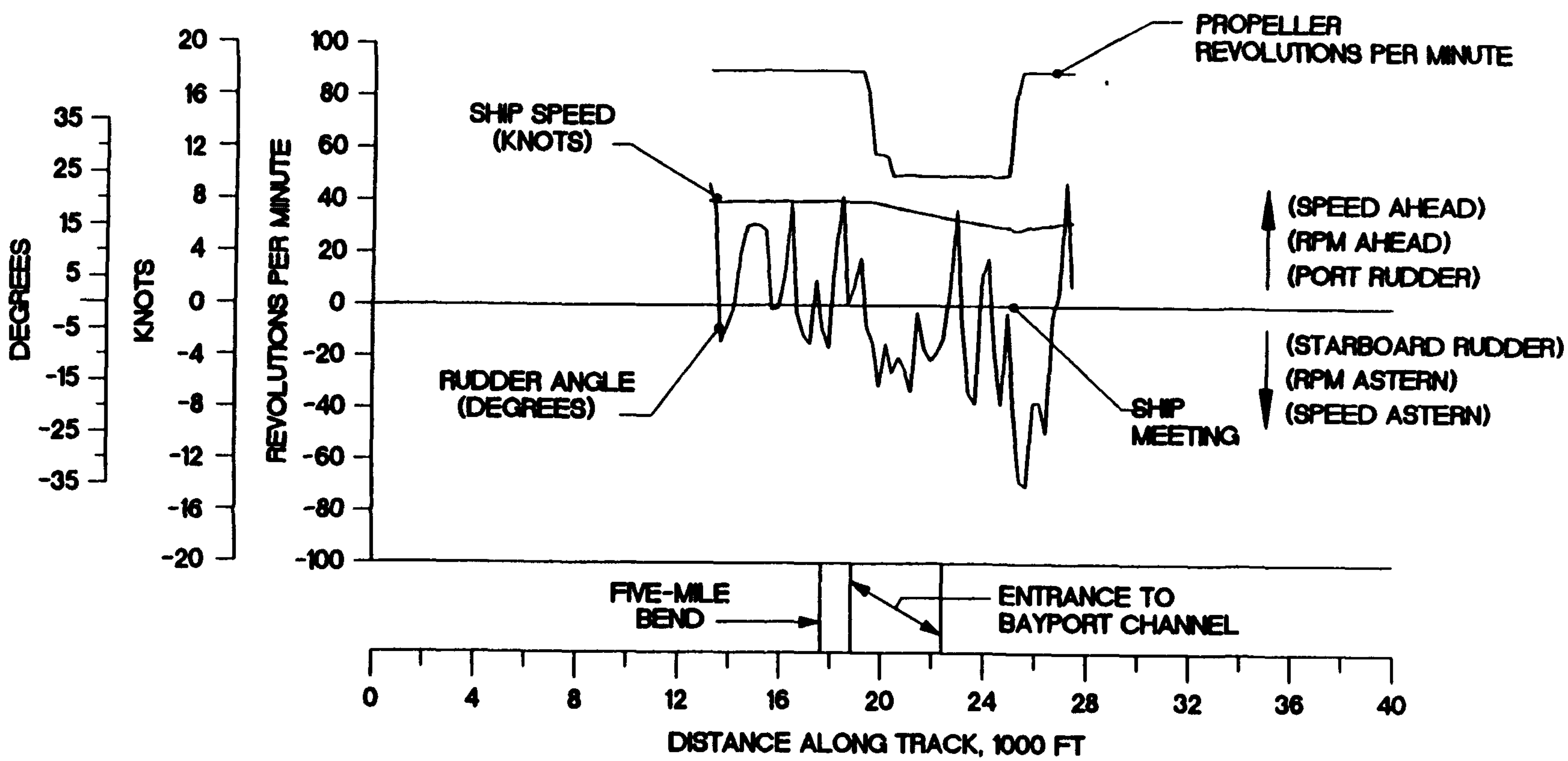


SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 1

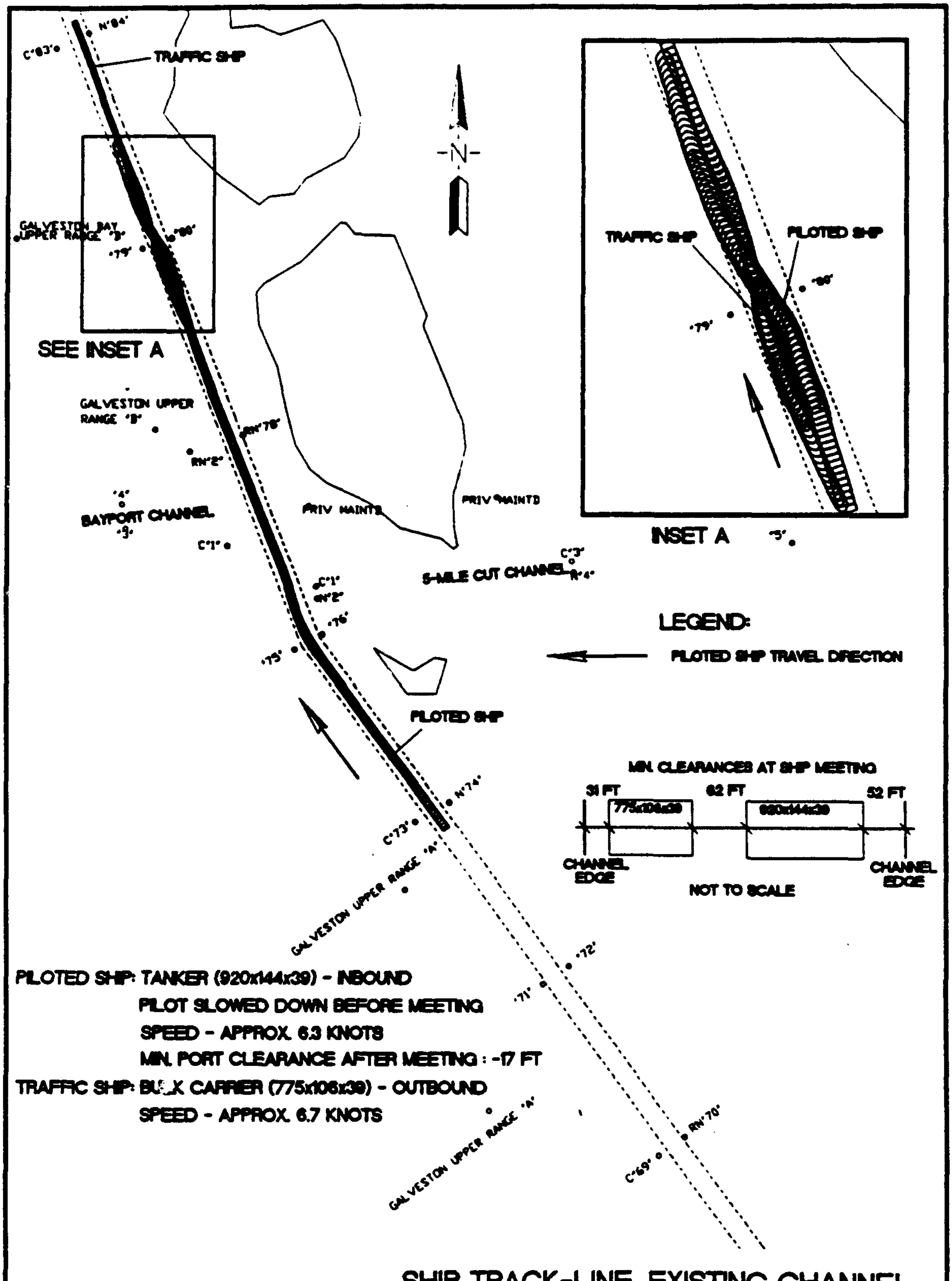
PLATE 1



PILOTED SHIP: TANKER (920x144x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 1

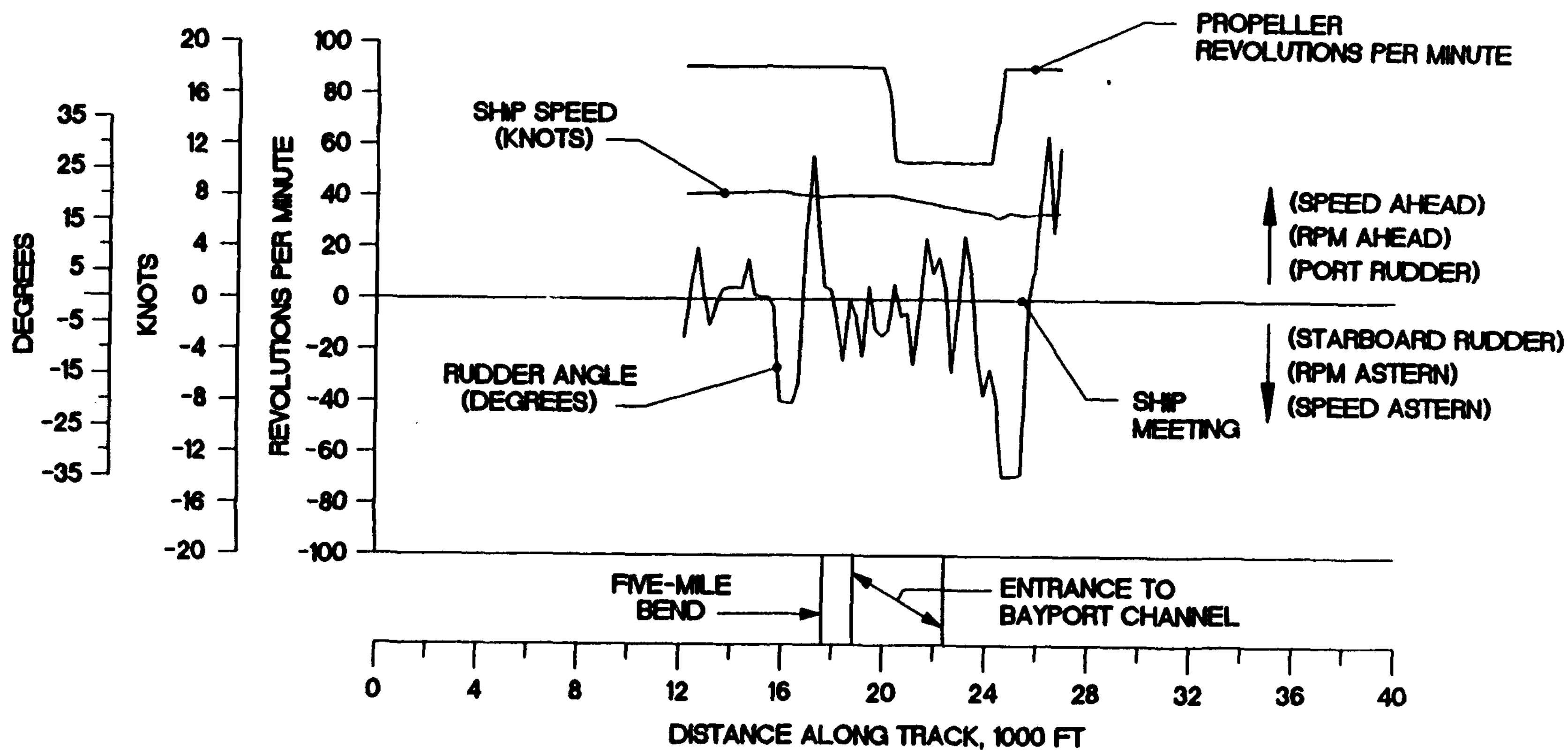
PLATE 2



SHIP TRACK-LINE, EXISTING CHANNEL

BAYPORT VICINITY

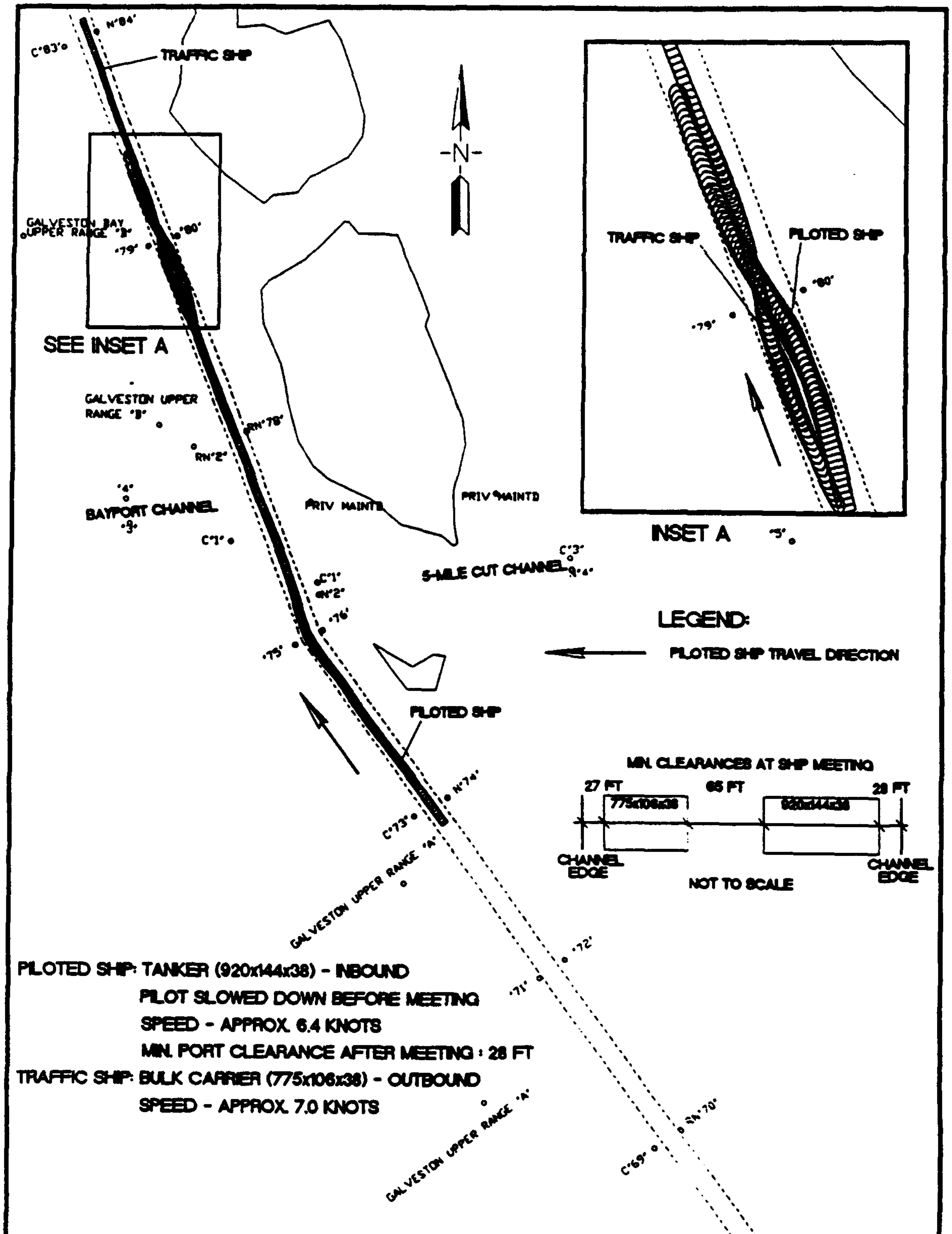
FLOOD TIDE, PILOT F, RUN 2



CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 2

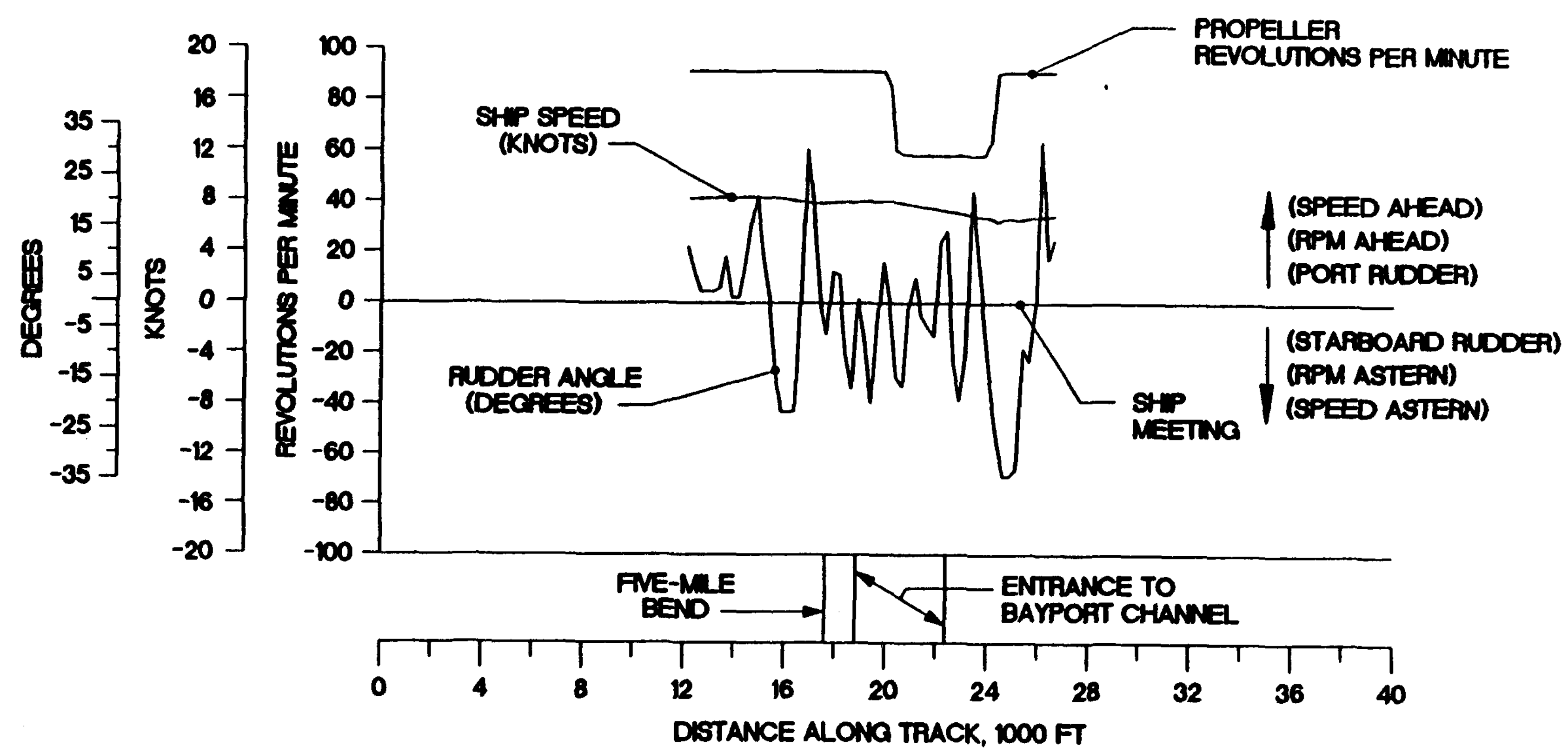
PILOTED SHIP: TANKER (920x144x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND

PLATE 4



SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 3

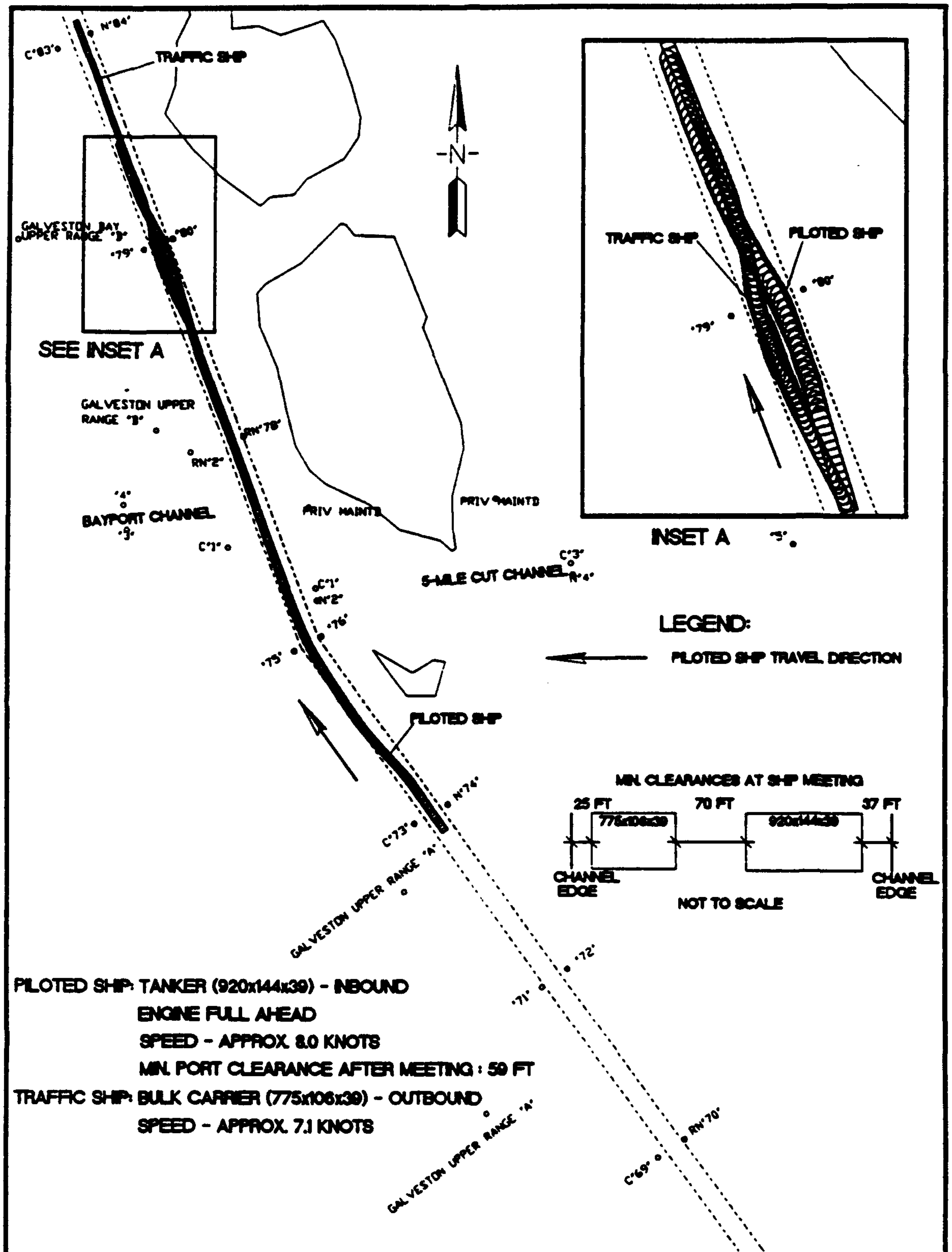
PLATE 5



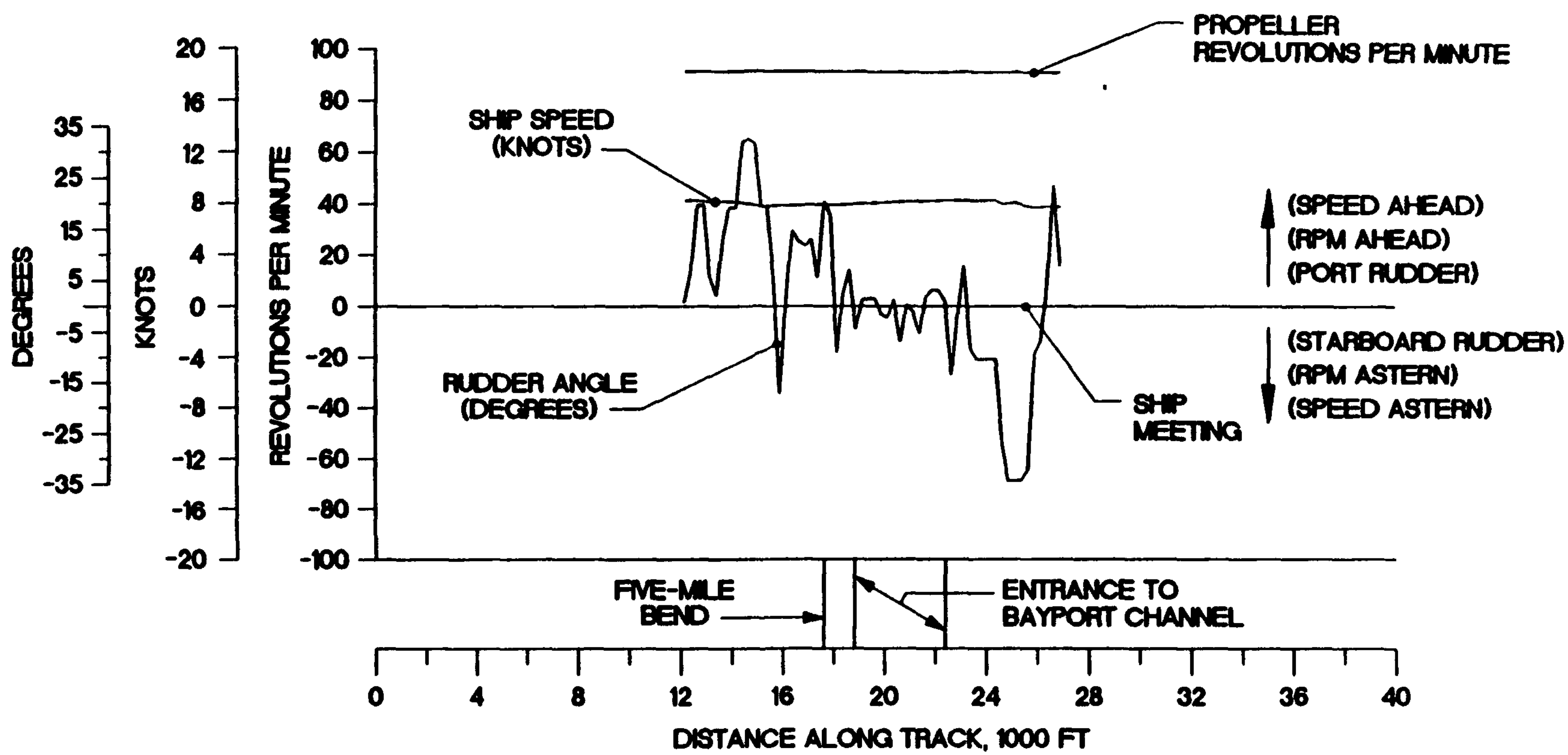
PILOTED SHIP: TANKER (920x144x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 3

PLATE 6



SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 1



PILOTED SHIP: TANKER (920x144x39) - INBOUND

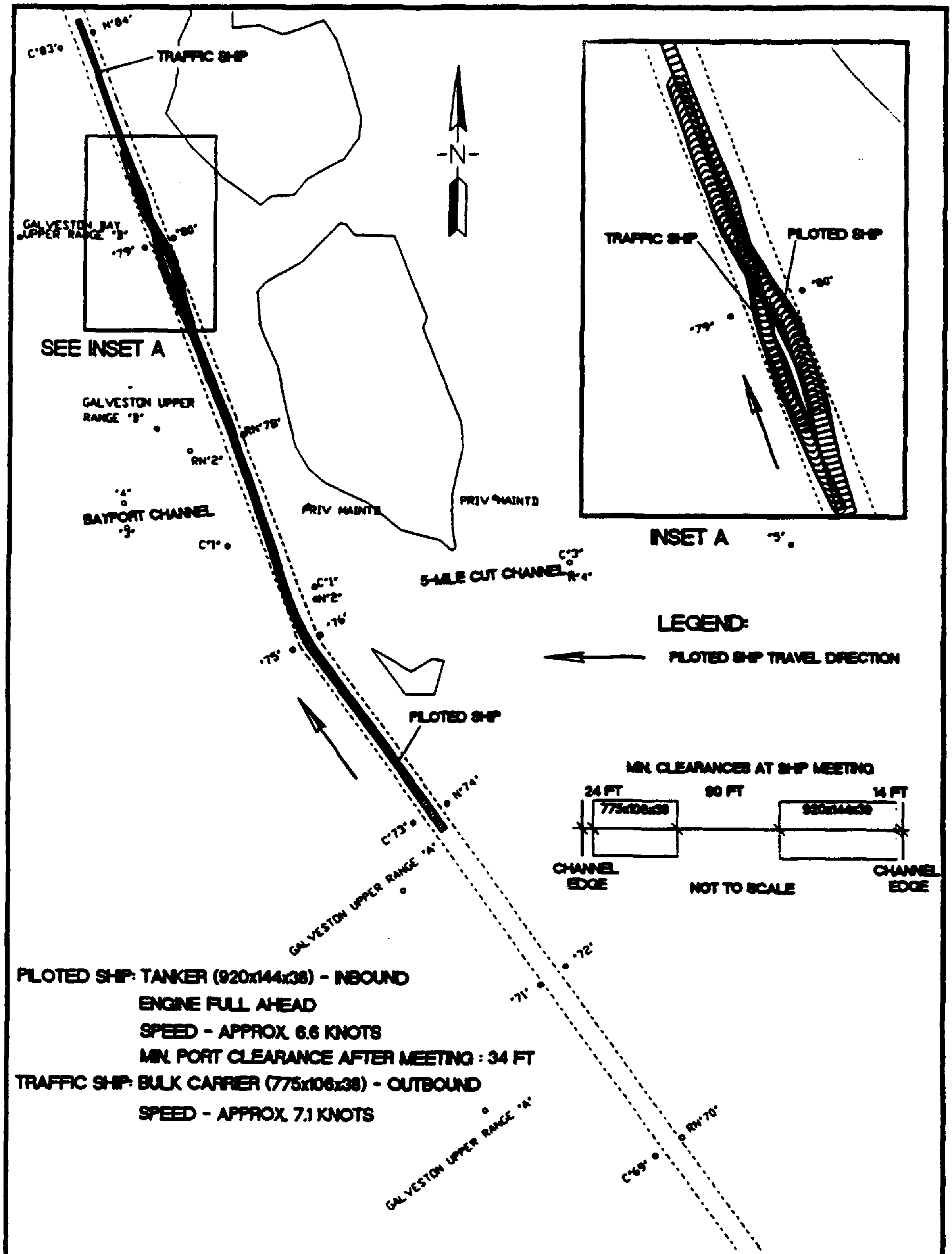
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL

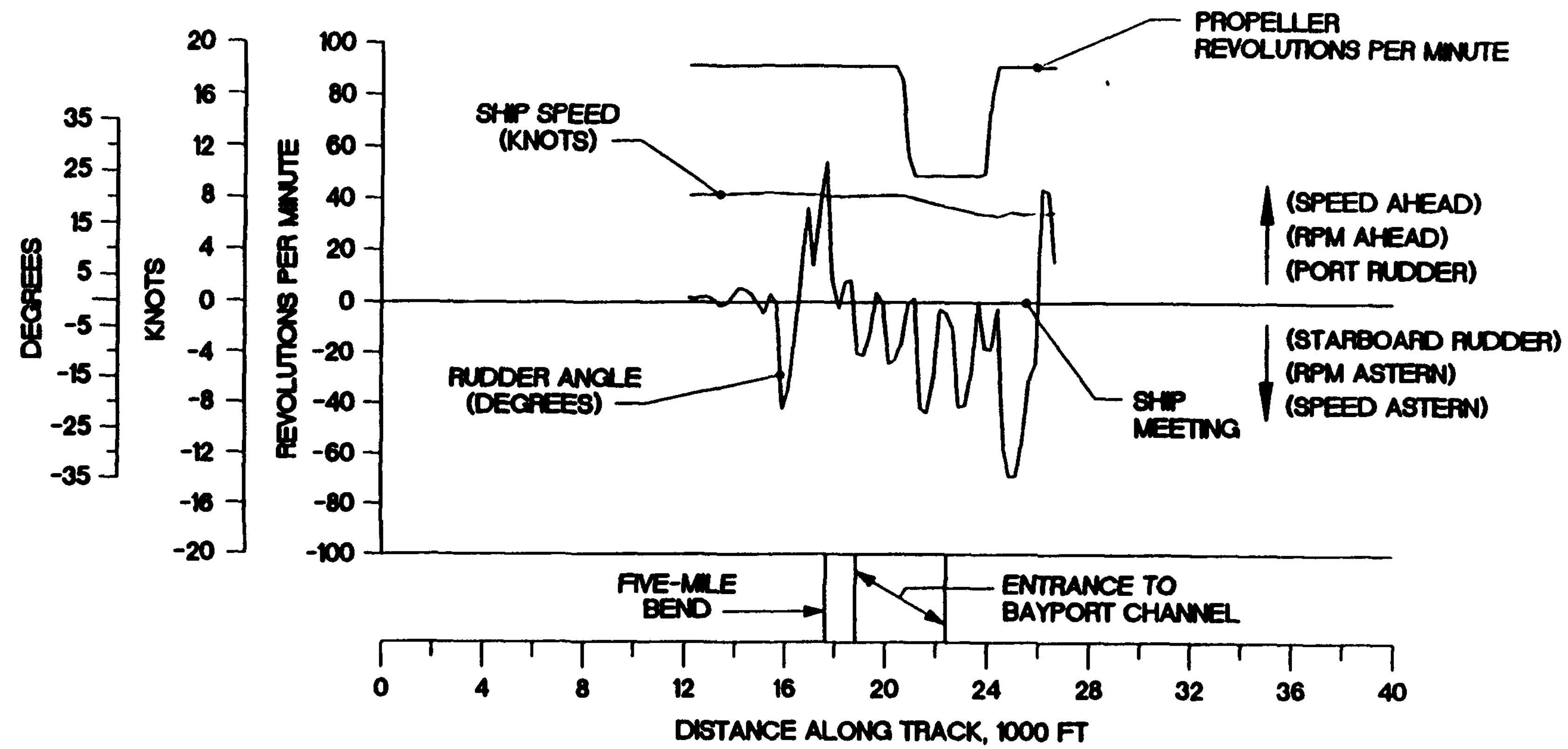
BAYPORT VICINITY

FLOOD TIDE, PILOT Q, RUN 1

PLATE 8



SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 2

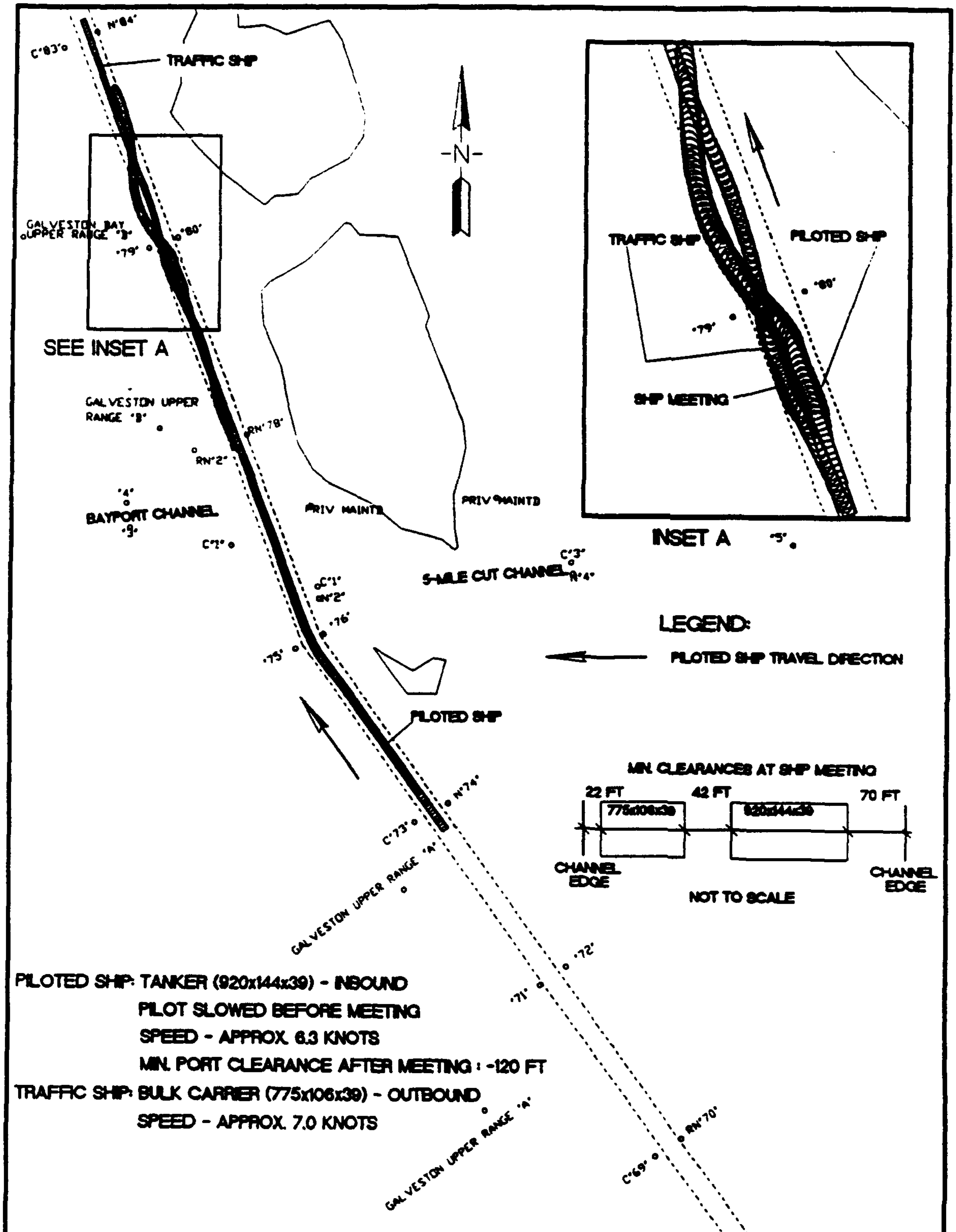


CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL

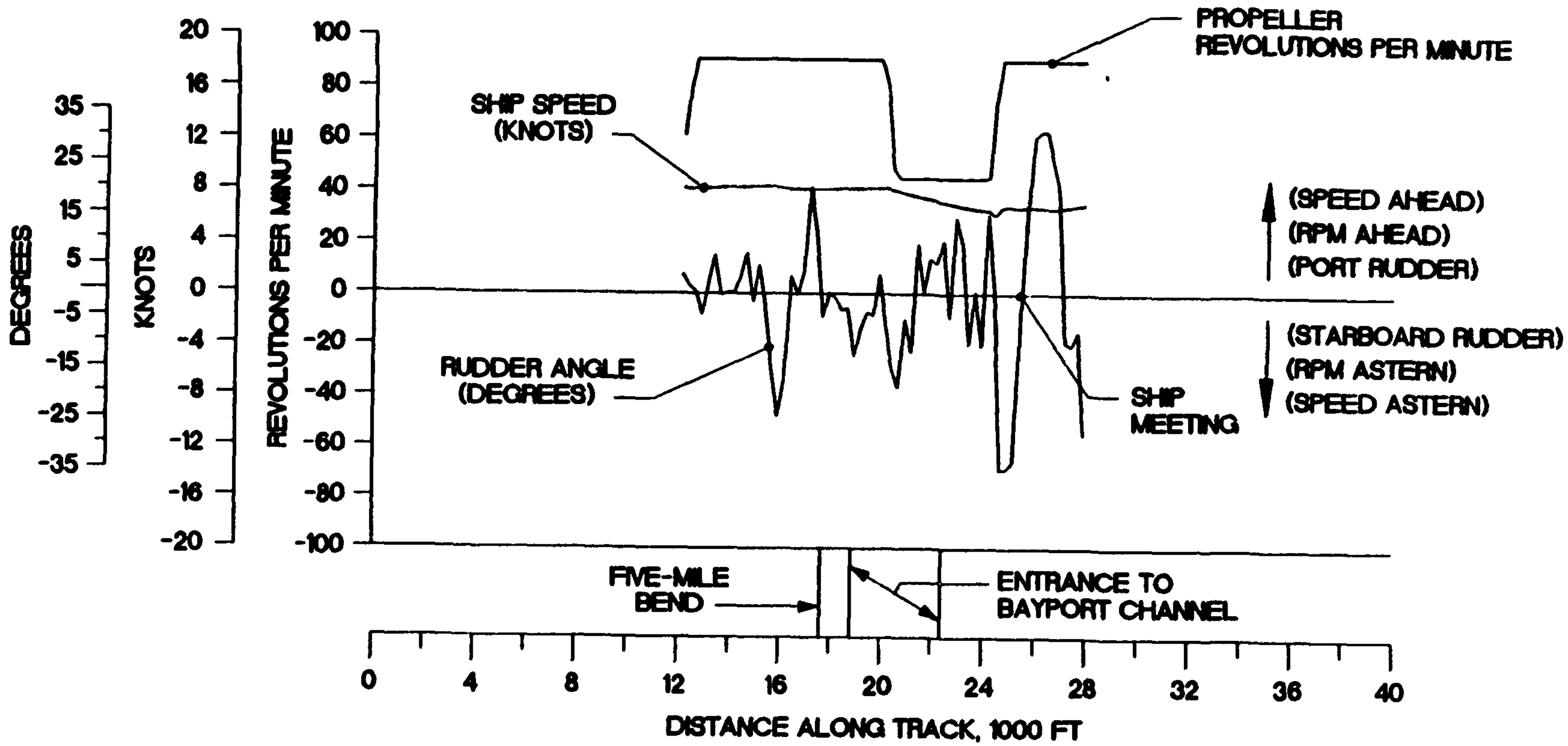
BAYPORT VICINITY
FLOOD TIDE, PILOT Q, RUN 2

PILOTED SHIP: TANKER (920x144x38) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x38) - OUTBOUND

PLATE 10

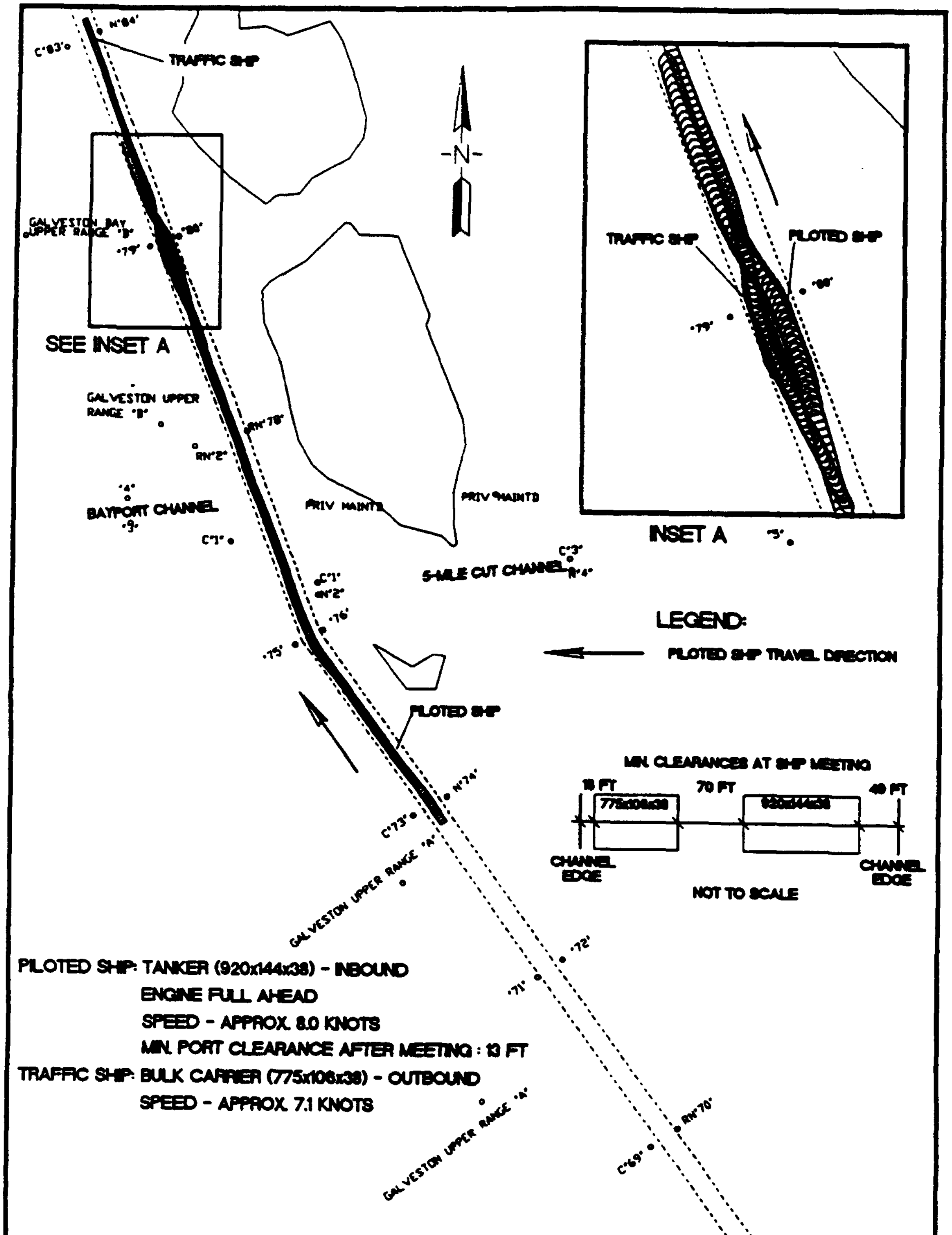


SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 1



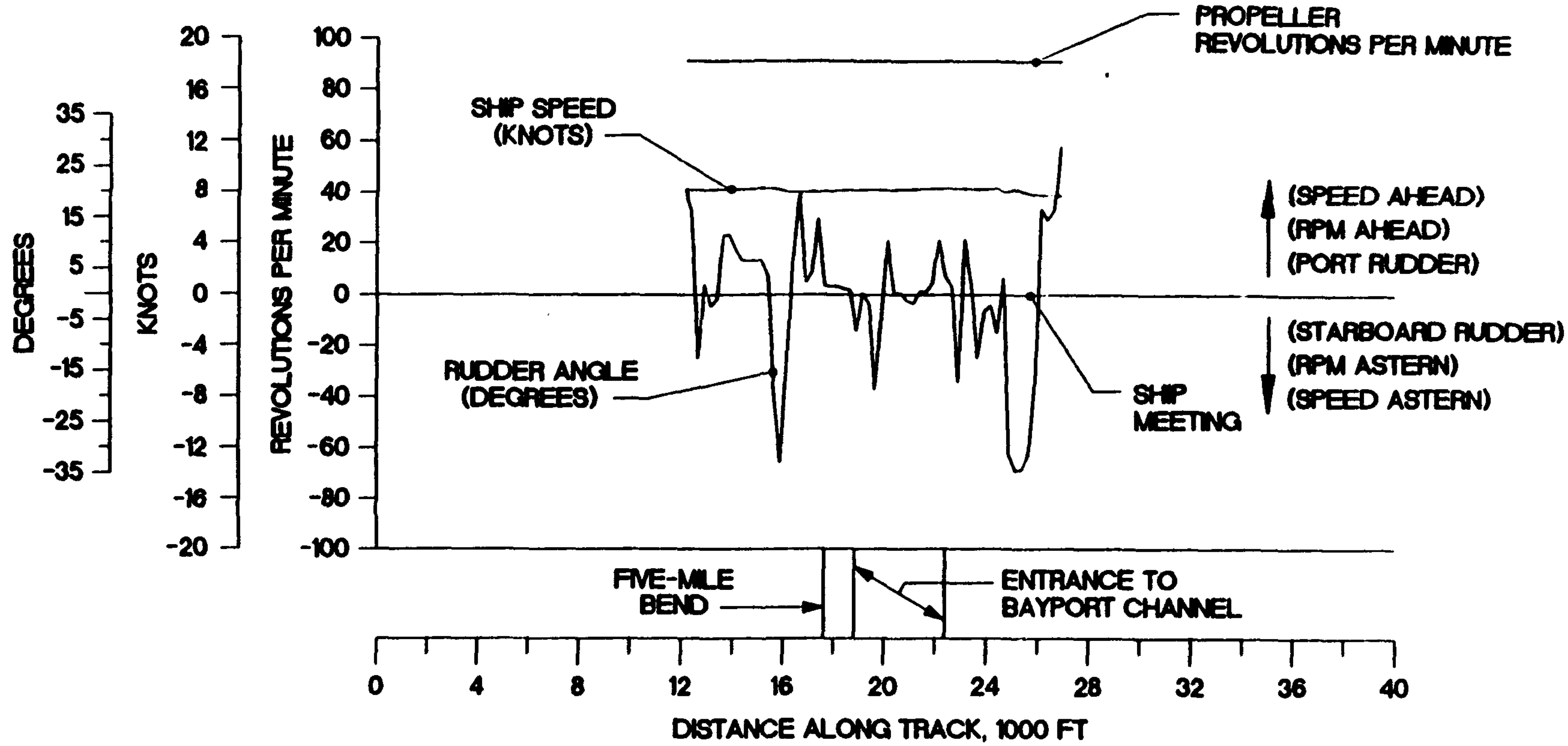
CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 1

PILOTED SHIP: TANKER (920x144x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND



SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 2

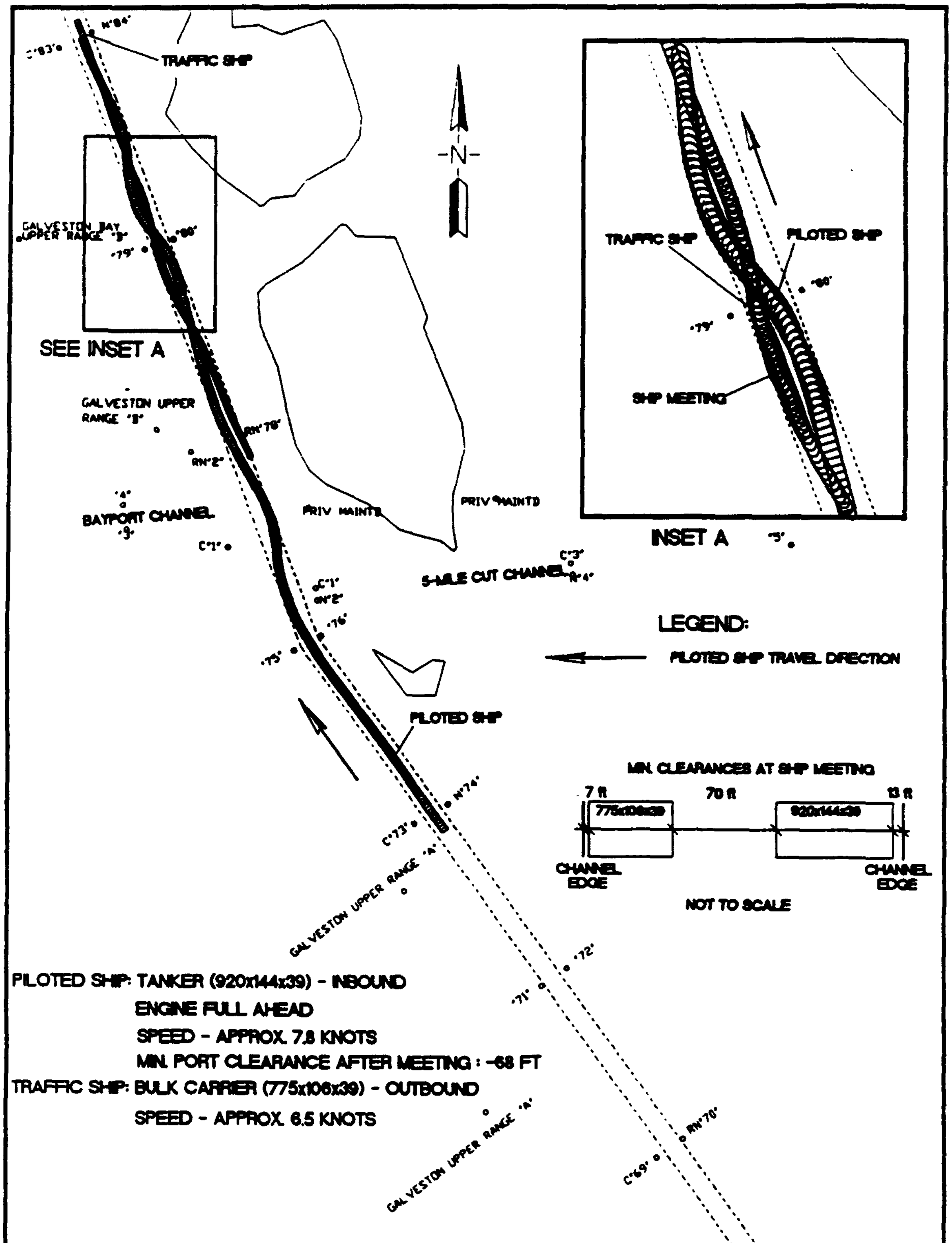
PLATE 13



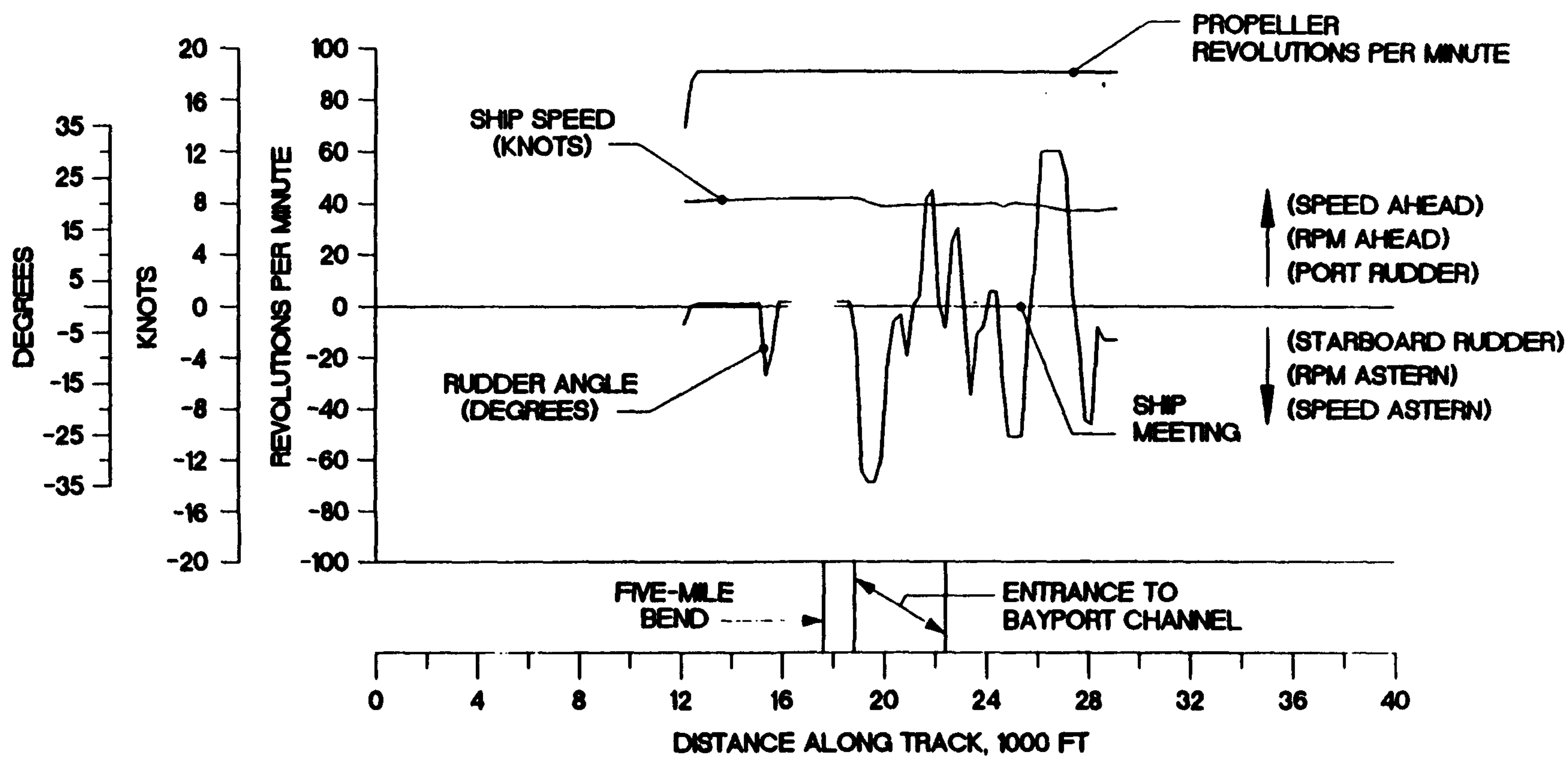
PILOTED SHIP: TANKER (920x144x38) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x38) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 2

PLATE 14



SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 1

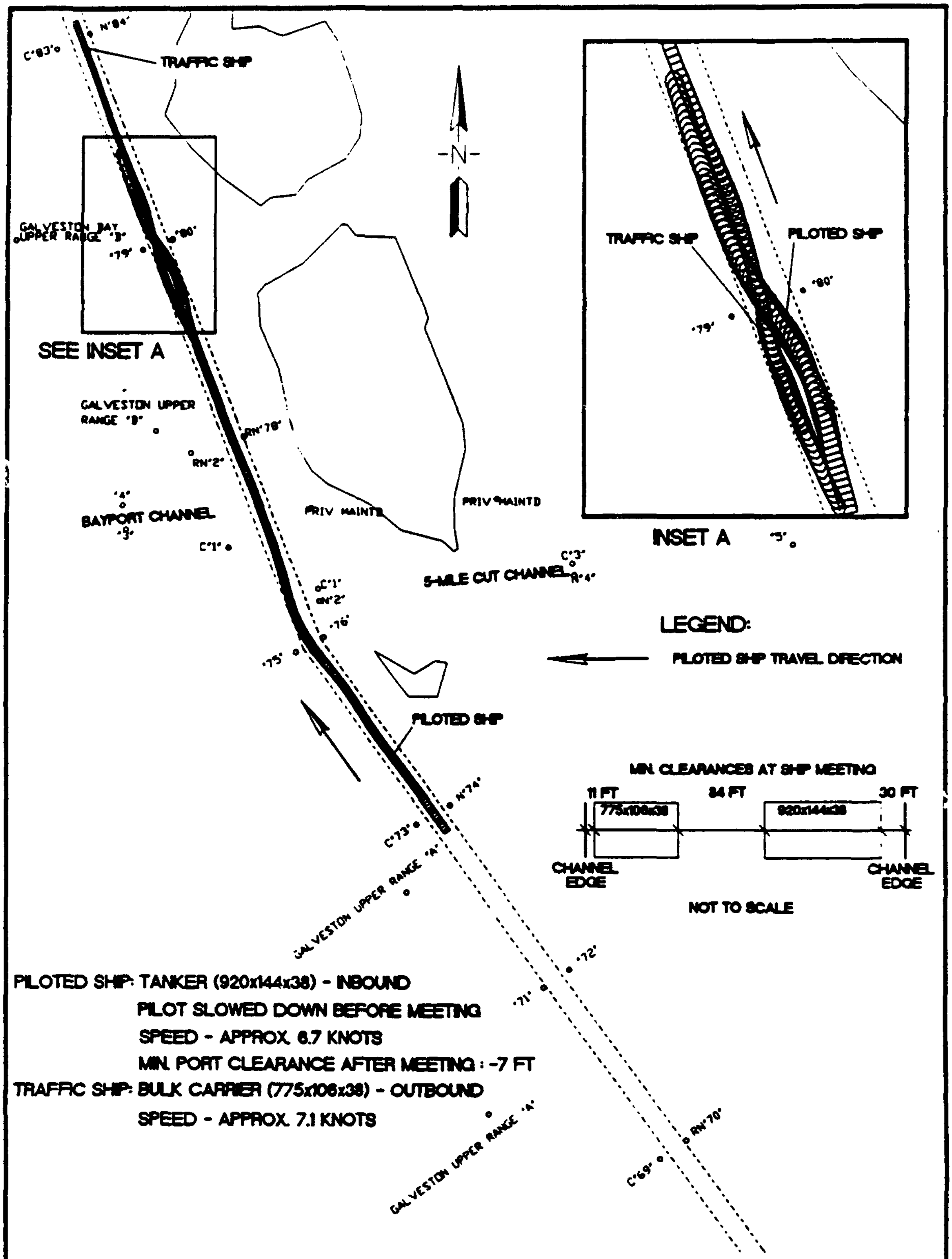


PILOTED SHIP: TANKER (920x144x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND

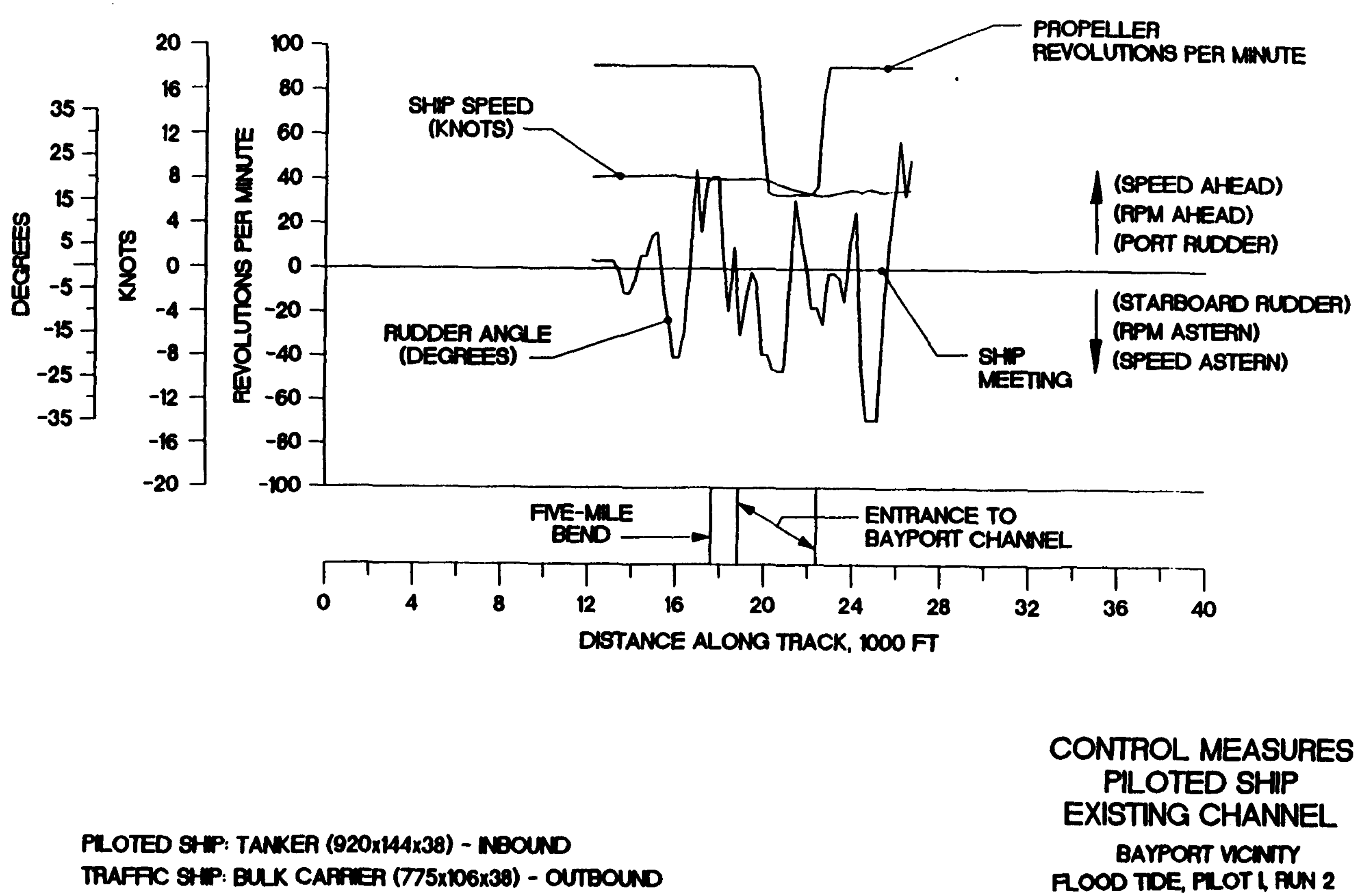
CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL

BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 1

PLATE 16



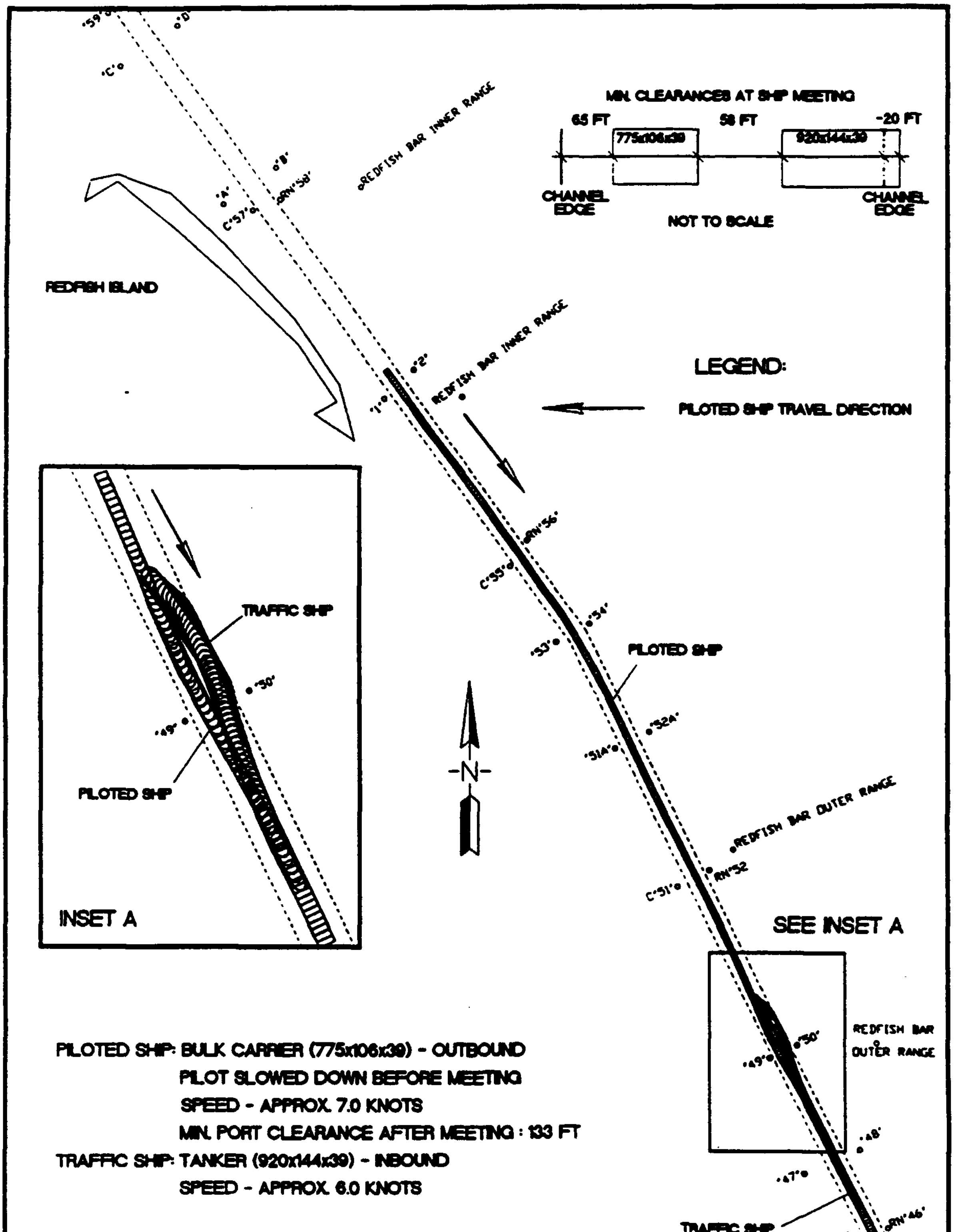
SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 2



CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL

BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 2

PLATE 18



PILOTED SHIP: BULK CARRIER (775x106x39) - OUTBOUND
PILOT SLOWED DOWN BEFORE MEETING
SPEED - APPROX. 7.0 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : 133 FT
TRAFFIC SHIP: TANKER (920x144x39) - INBOUND
SPEED - APPROX. 6.0 KNOTS

SHIP TRACK-LINE, EXISTING CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F

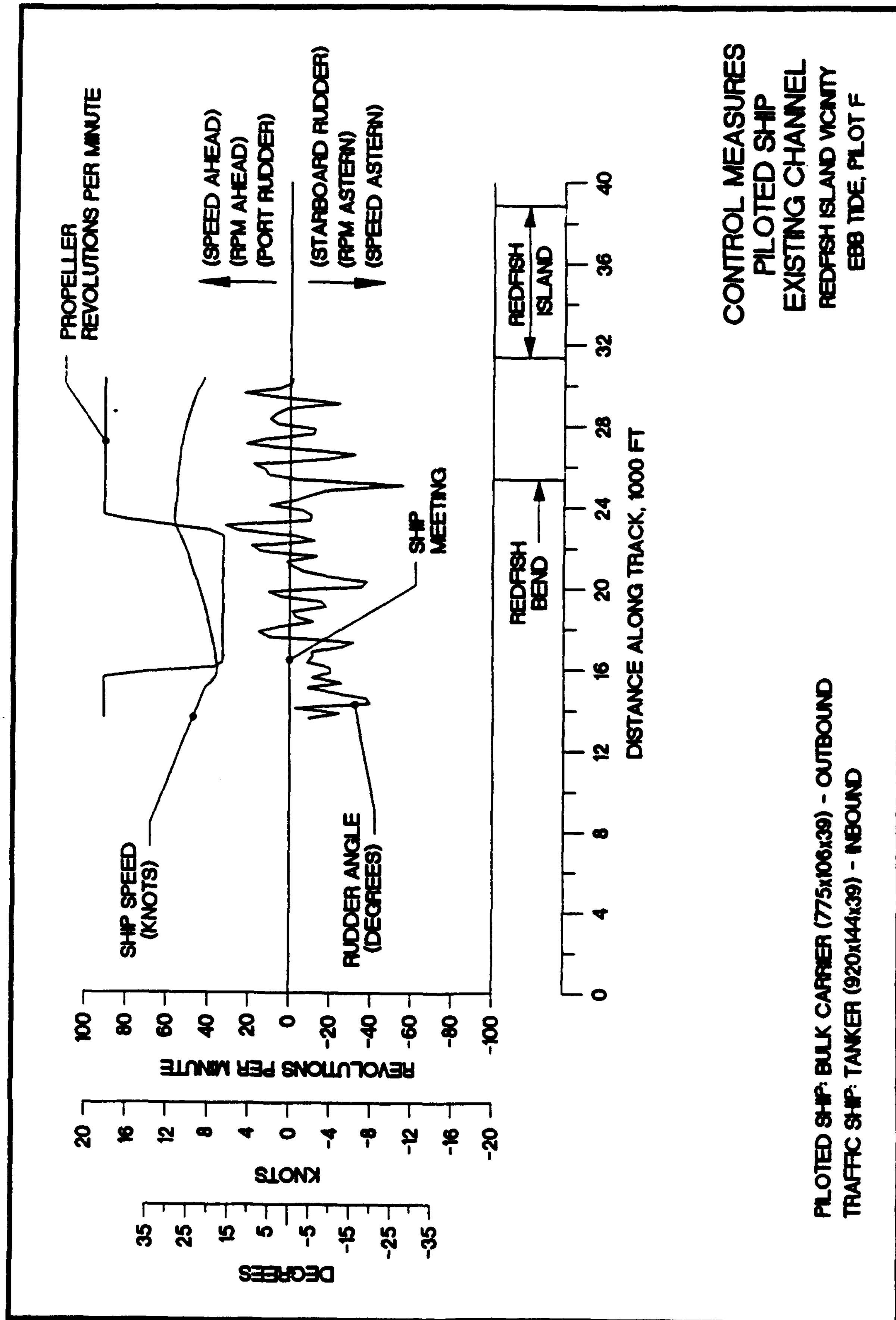
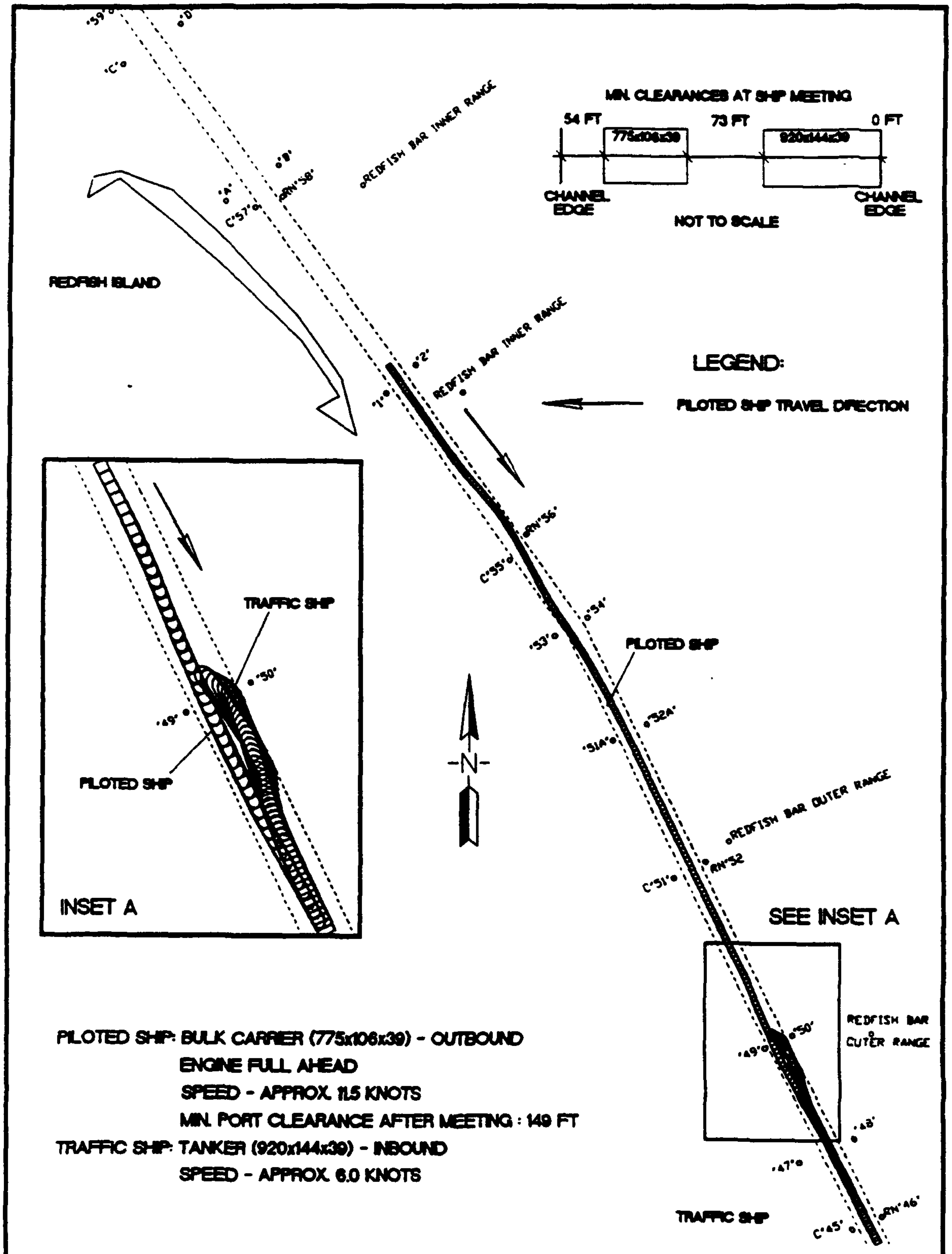
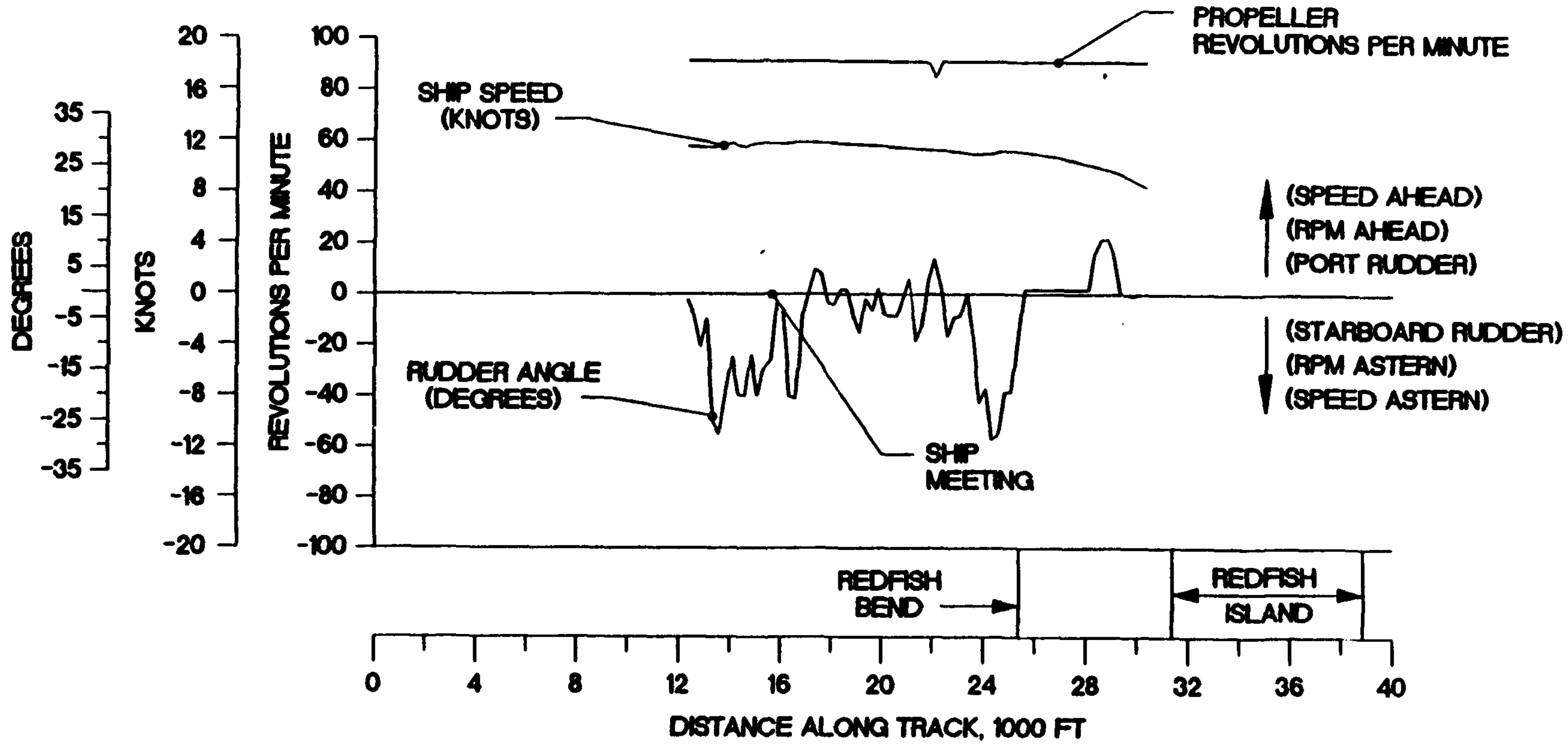

CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F
PROPELLER REVOLUTIONS PER MINUTE
(SPEED AHEAD)
(RPM AHEAD)
(PORT RUDDER)
(STARBOARD RUDDER)
(RPM ASTERN)
(SPEED ASTERN)
SHIP SPEED (KNOTS)
RUDDER ANGLE (DEGREES)
SHIP MEETING
REDFISH BEND
REDFISH ISLAND
0 4 8 12 16 20 24 28 32 36 40
DISTANCE ALONG TRACK, 1000 FT
100 80 60 40 20 0 -20 -40 -60 -80 -100
REVOLUTIONS PER MINUTE
20 16 12 8 4 0 -4 -8 -12 -16 -20
KNOTS
35 25 15 5 -5 -15 -25 -35
DEGREES
PILOTED SHIP: BULK CARRIER (775x106x39) - OUTBOUND
TRAFFIC SHIP: TANKER (920x144x39) - INBOUND

PLATE 20



SHIP TRACK-LINE, EXISTING CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT G

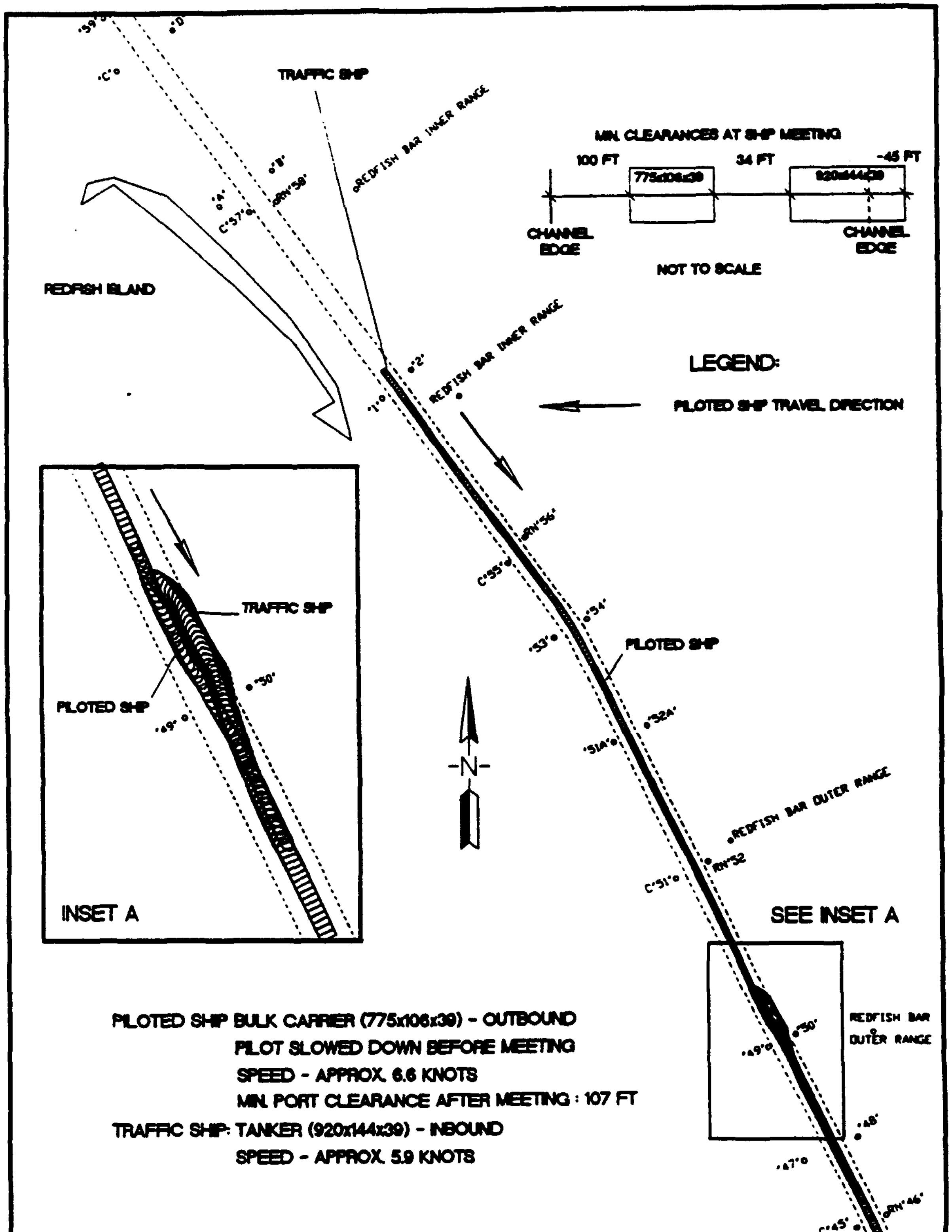
PLATE 21



PILOTED SHIP: BULK CARRIER (775x106x39) - OUTBOUND
TRAFFIC SHIP: TANKER (920x144x39) - INBOUND

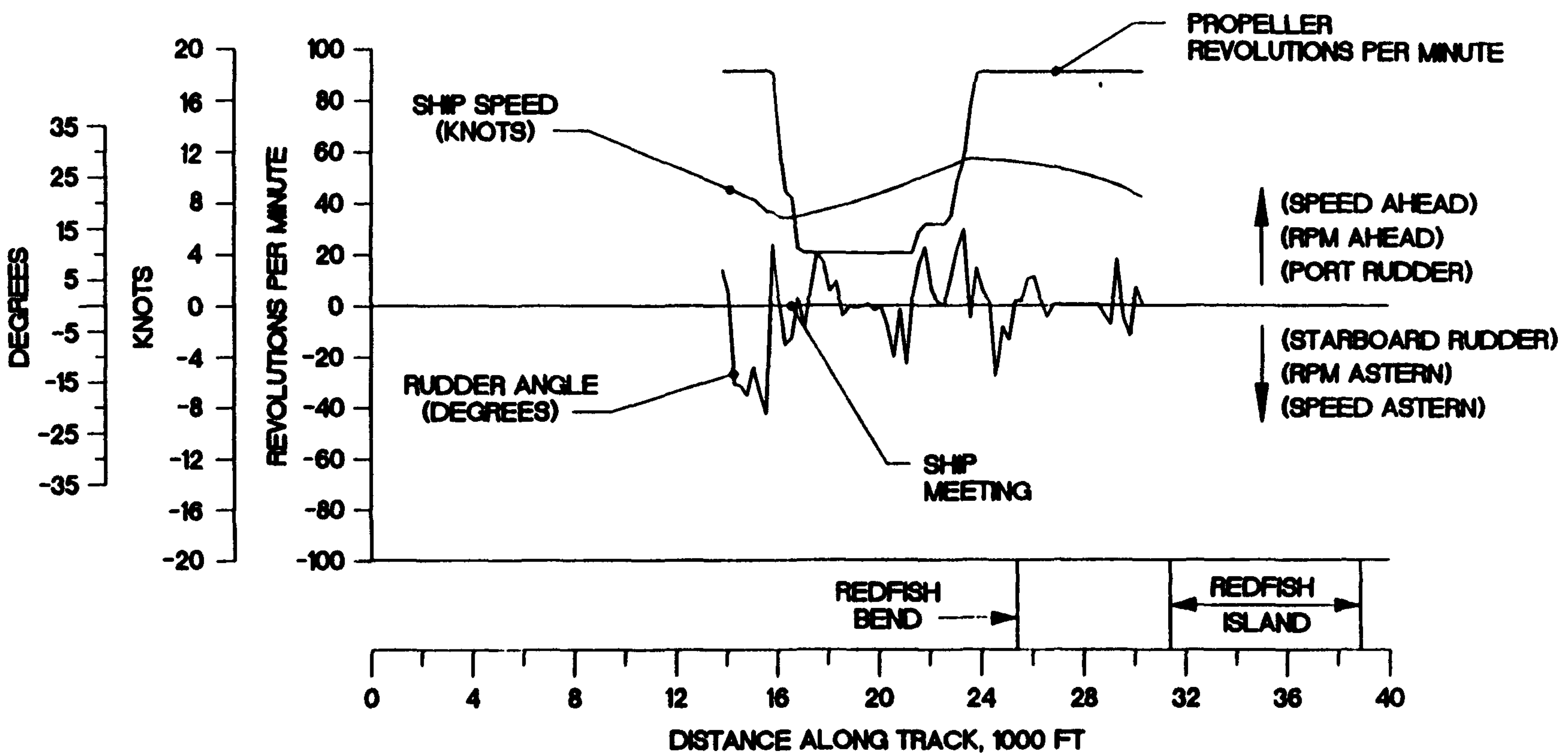
CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT G

PLATE 22



PILOTED SHIP BULK CARRIER (775x106x39) - OUTBOUND
PILOT SLOWED DOWN BEFORE MEETING
SPEED - APPROX. 6.6 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : 107 FT
TRAFFIC SHIP: TANKER (920x144x39) - INBOUND
SPEED - APPROX. 5.9 KNOTS

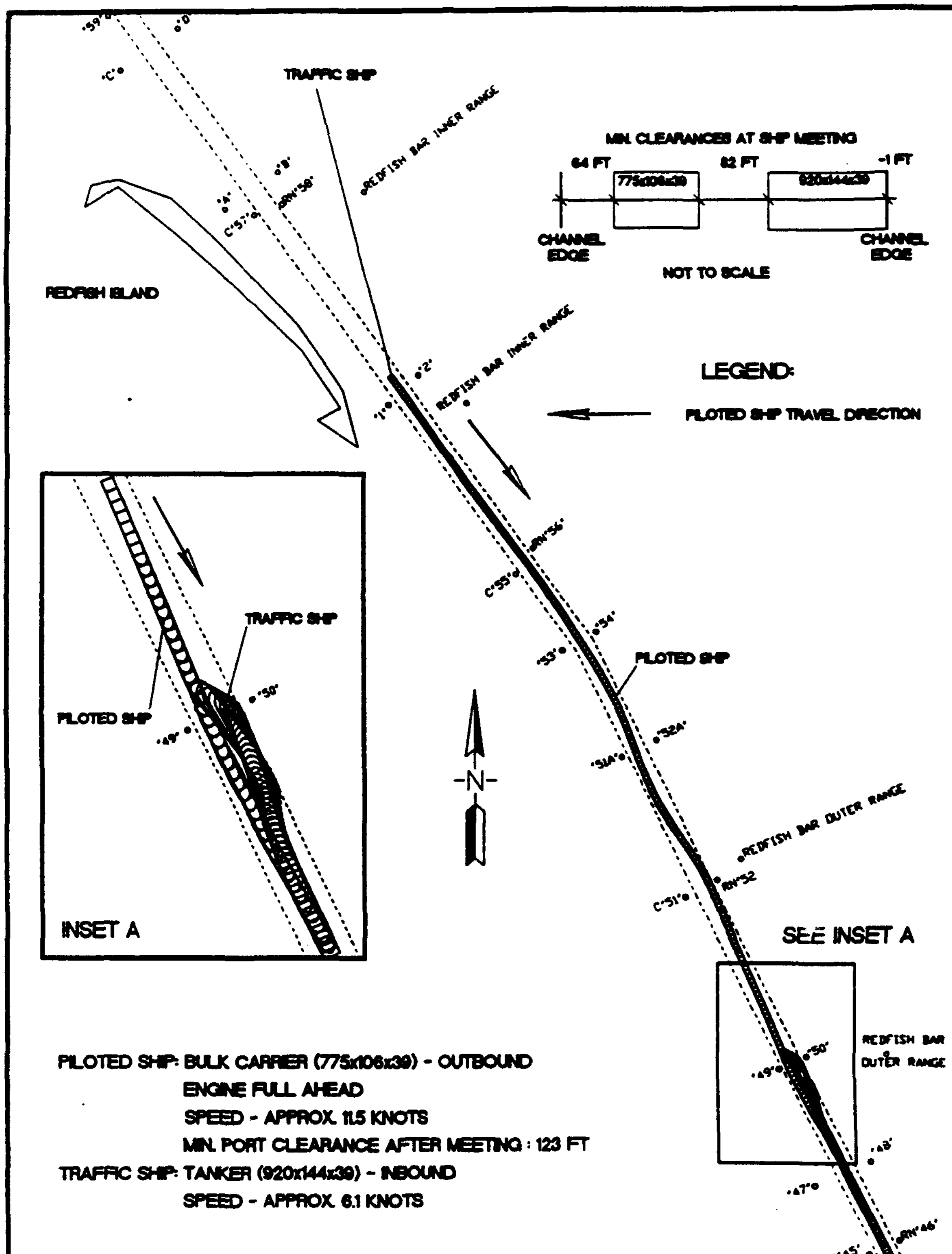
SHIP TRACK-LINE, EXISTING CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H



CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H

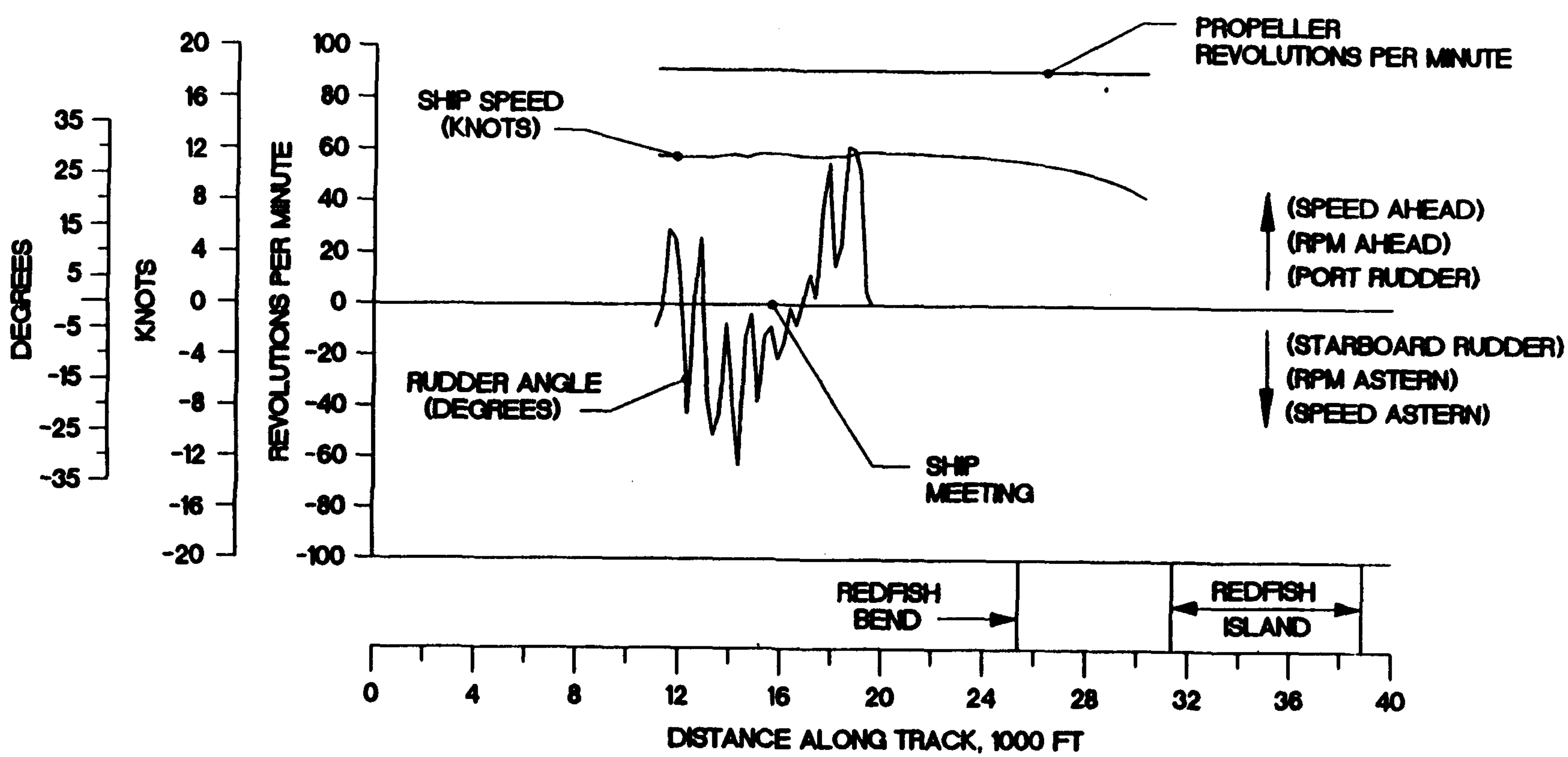
PILOTED SHIP: BULK CARRIER (775x106x39) - OUTBOUND
TRAFFIC SHIP: TANKER (920x144x39) - INBOUND

PLATE 24



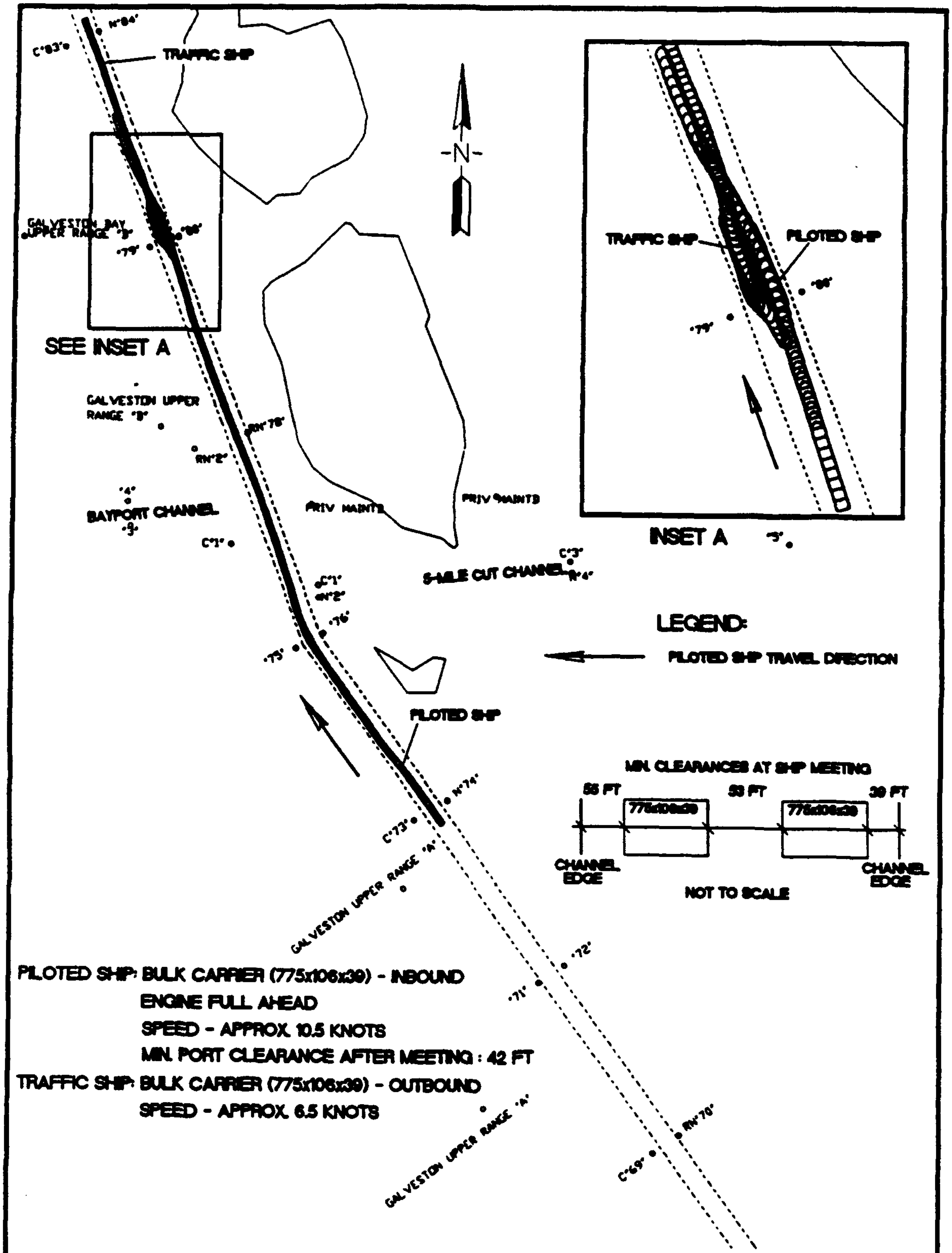
PILOTED SHIP: BULK CARRIER (775x106x39) - OUTBOUND
ENGINE FULL AHEAD
SPEED - APPROX. 11.5 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : 123 FT
TRAFFIC SHIP: TANKER (920x144x39) - INBOUND
SPEED - APPROX. 6.1 KNOTS

SHIP TRACK-LINE, EXISTING CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT I

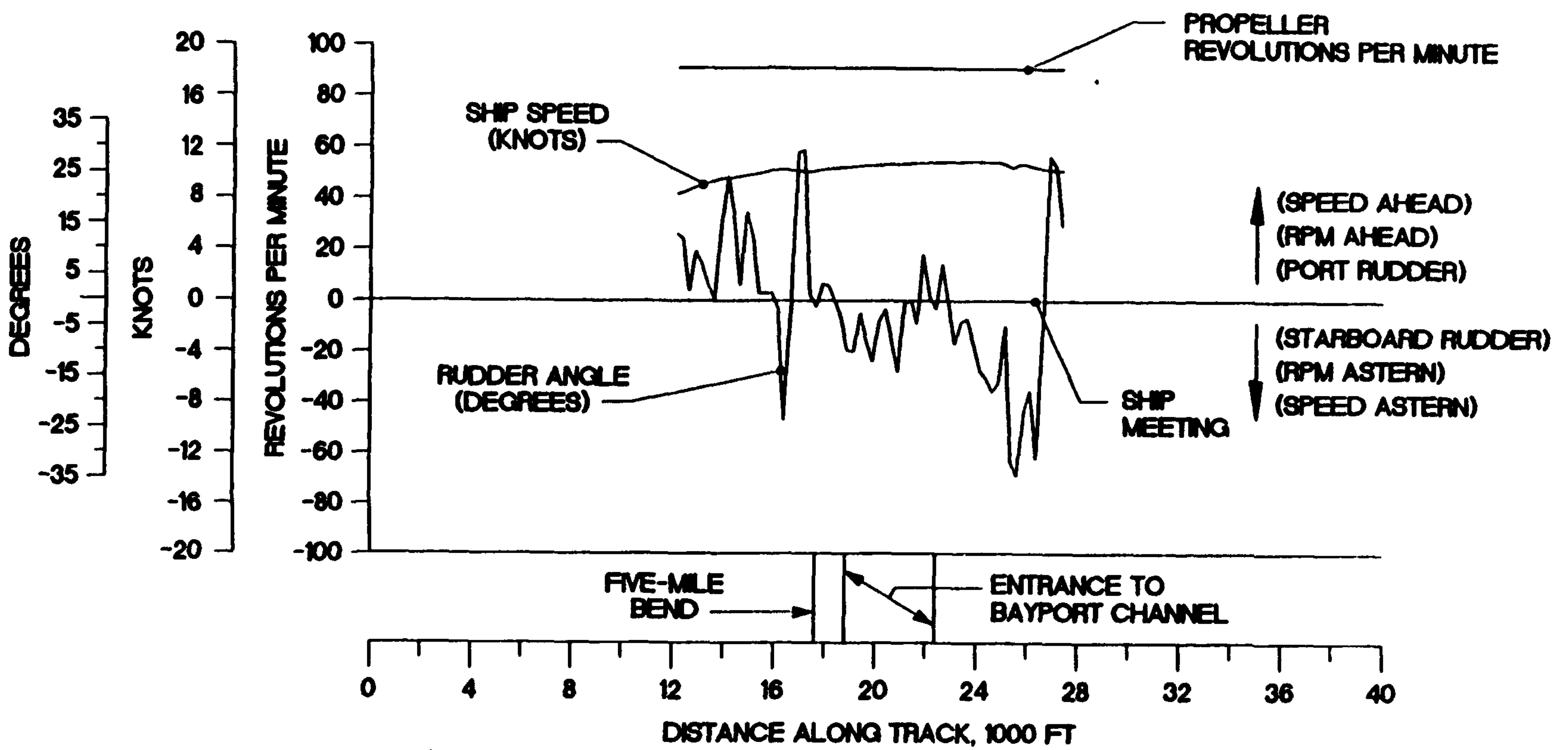


PILOTED SHIP: BULK CARRIER (775x106x39) - OUTBOUND
TRAFFIC SHIP: TANKER (920x144x39) - INBOUND

CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT I



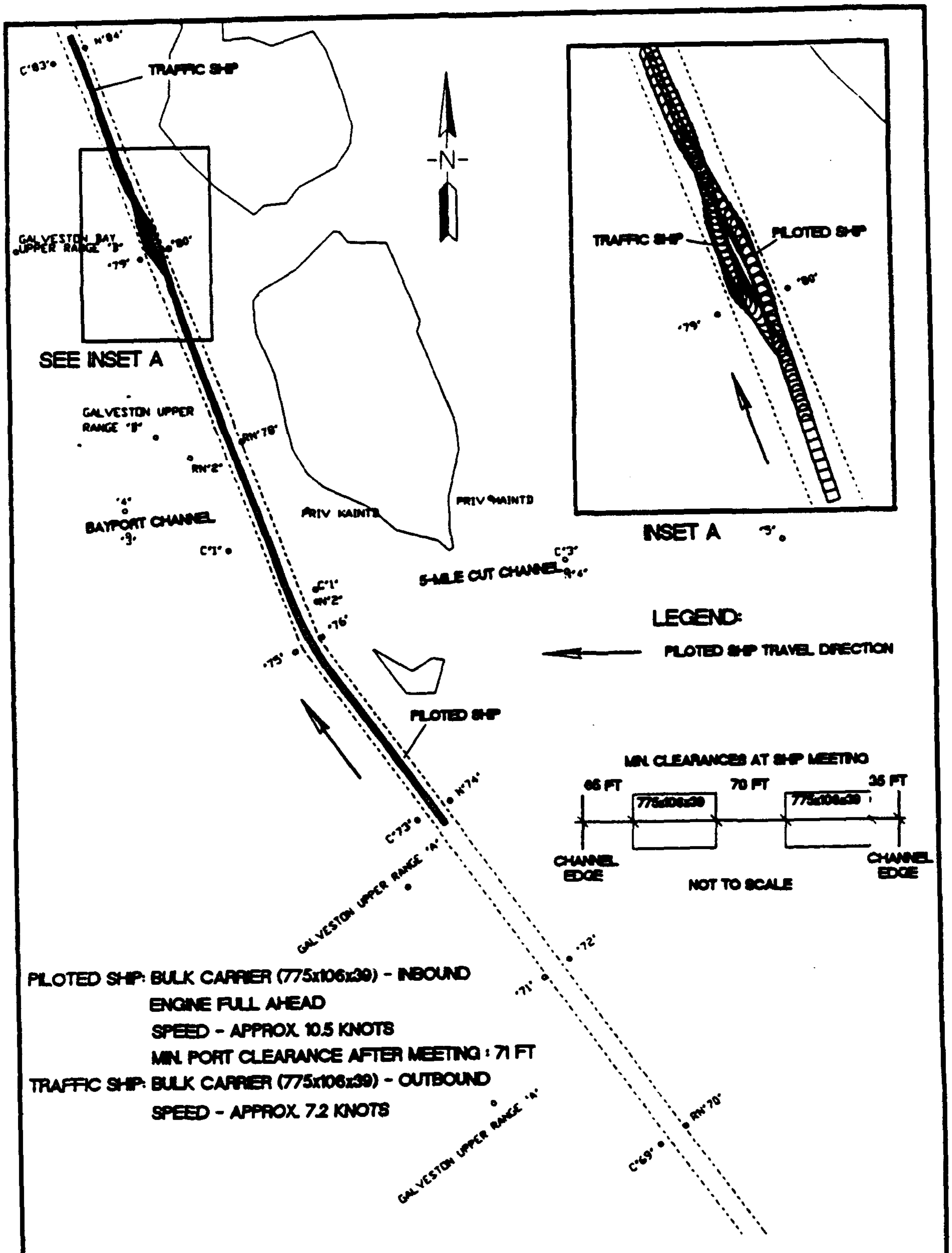
SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 3



PILOTED SHIP: BULK CARRIER (775x106x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND

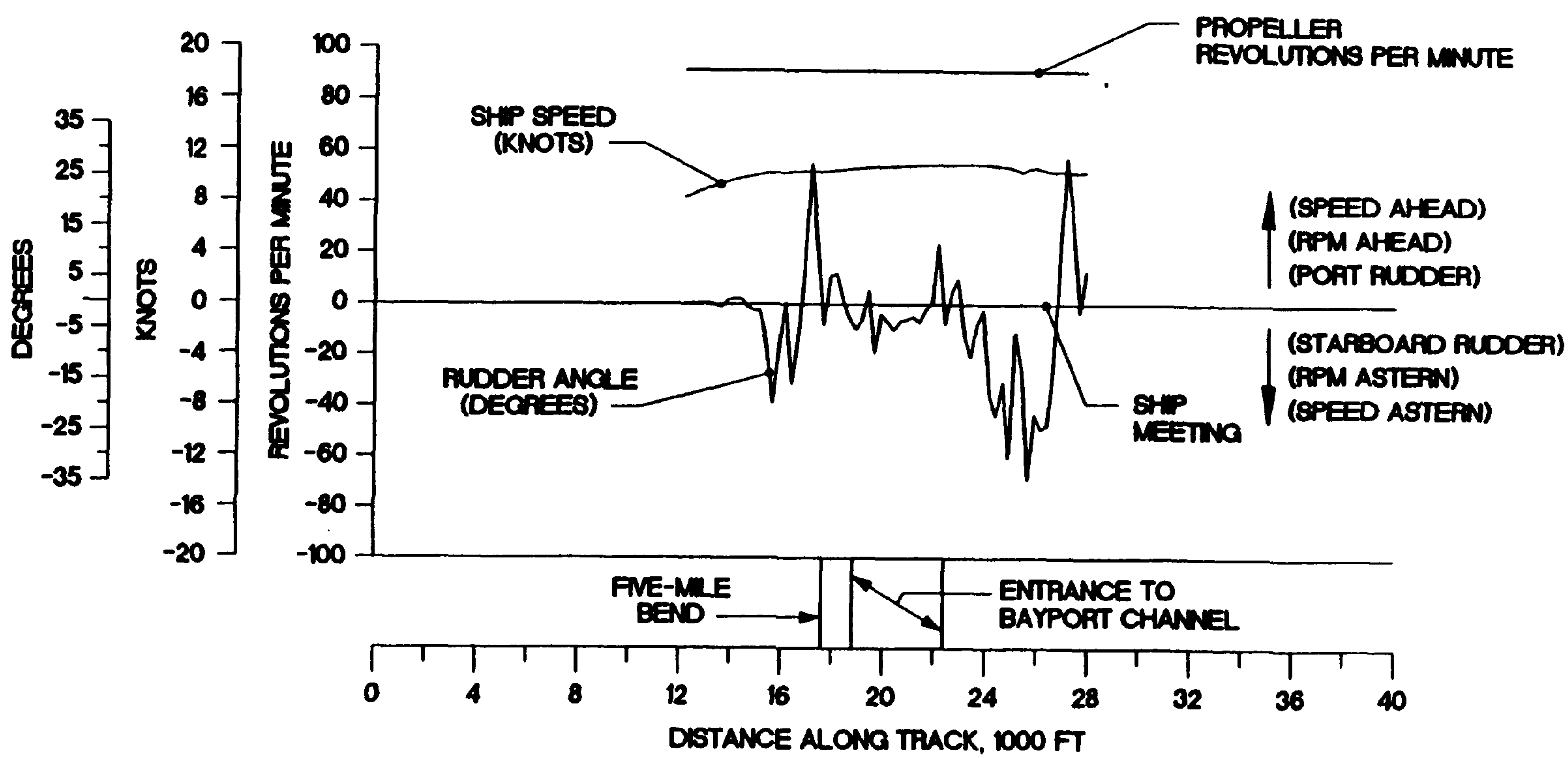
CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 3

PLATE 28



SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 3

PLATE 29

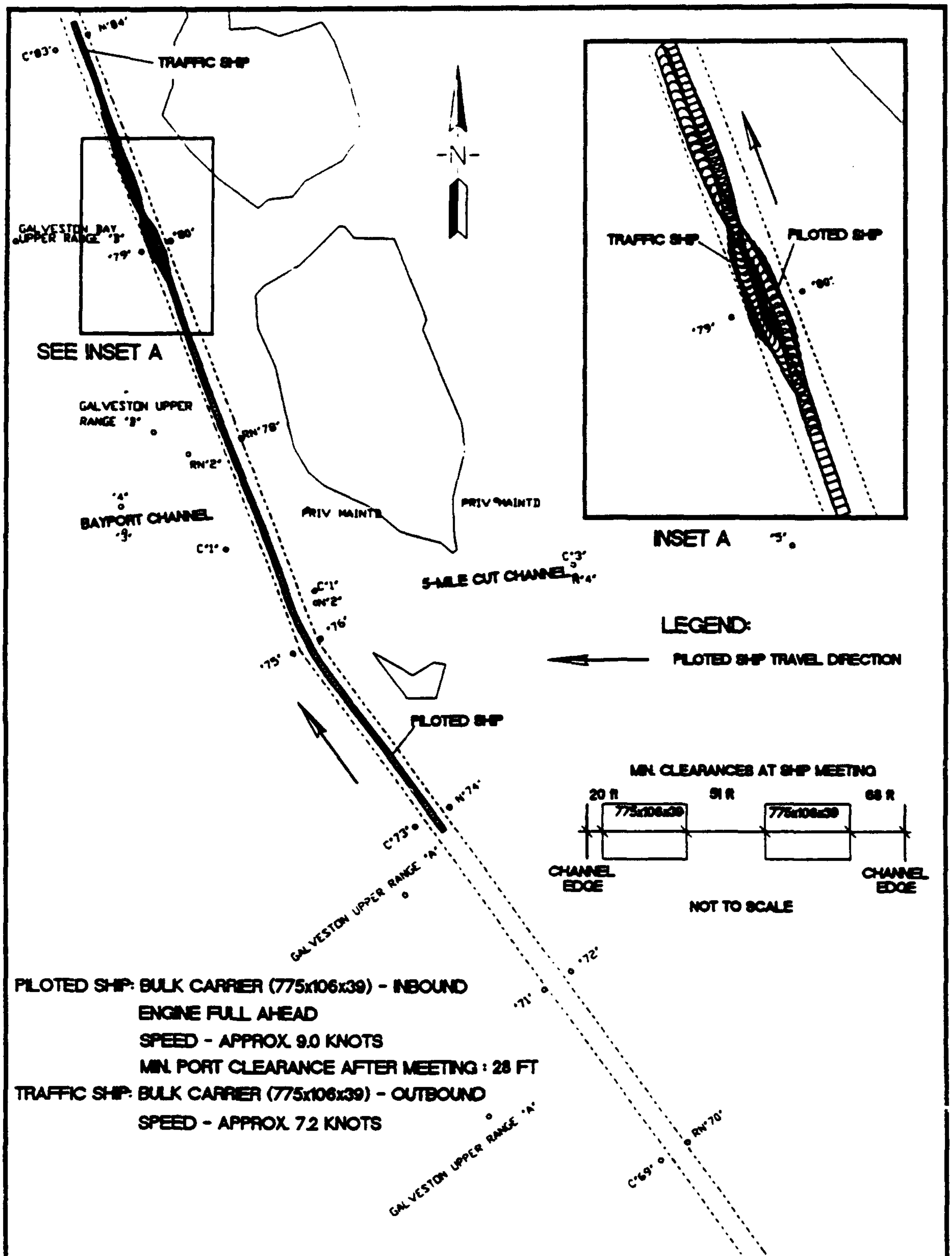


PILOTED SHIP: BULK CARRIER (775x106x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL

BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 3

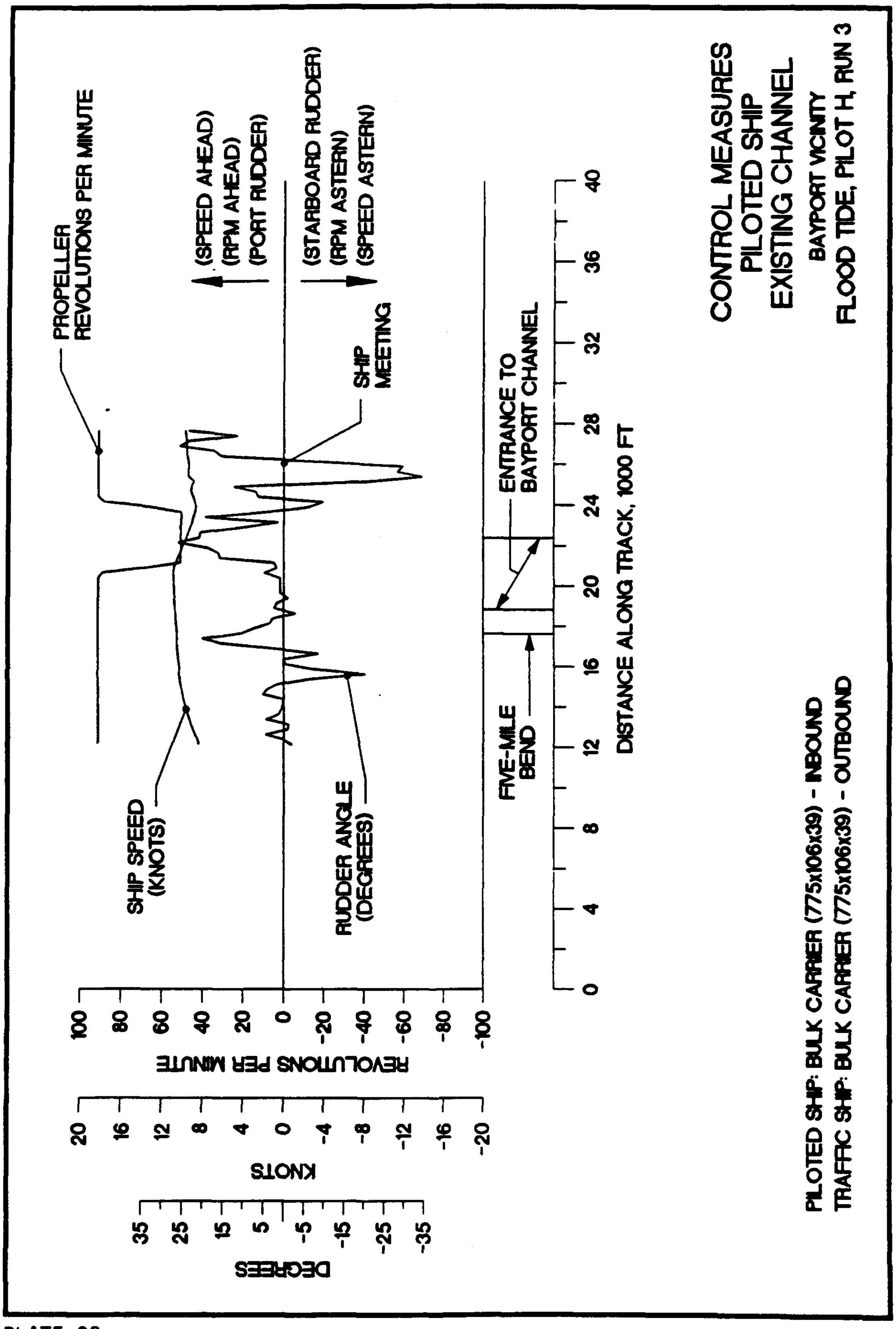
PLATE 30



SHIP TRACK-LINE, EXISTING CHANNEL

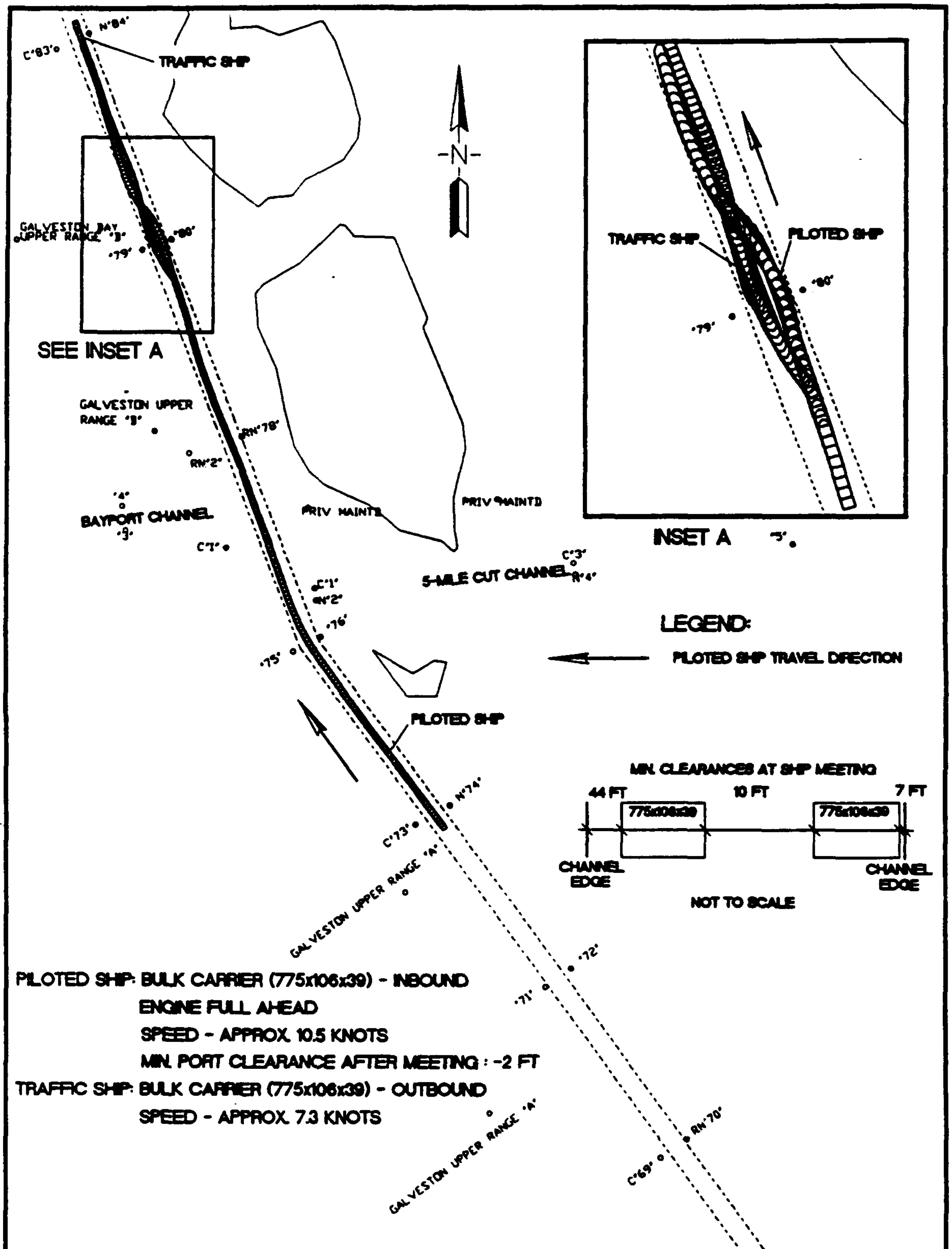
BAYPORT VICINITY

FLOOD TIDE, PILOT H, RUN 3



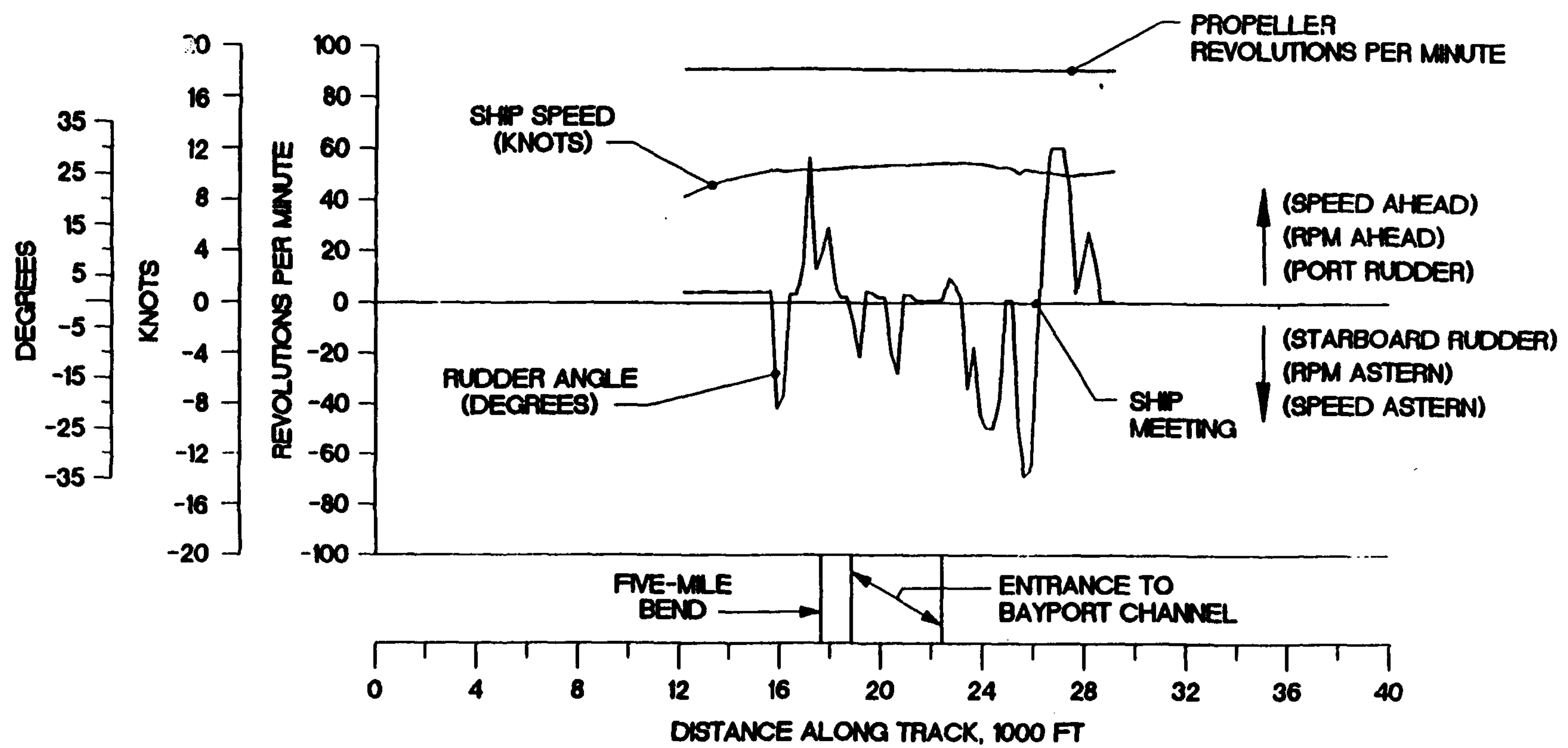
CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 3
PILOTED SHIP: BULK CARRIER (775x106x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND
PROPELLER REVOLUTIONS PER MINUTE
(SPEED AHEAD)
(RPM AHEAD)
(PORT RUDDER)
(STARBOARD RUDDER)
(RPM ASTERN)
(SPEED ASTERN)
SHIP MEETING
SHIP SPEED (KNOTS)
RUDDER ANGLE (DEGREES)
ENTRANCE TO BAYPORT CHANNEL
FIVE-MILE BEND
DISTANCE ALONG TRACK, 1000 FT
0
4
8
12
16
20
24
28
32
36
40
REVOLUTIONS PER MINUTE
100
80
60
40
20
0
-20
-40
-60
-80
-100
KNOTS
20
16
12
8
4
0
-4
-8
-12
-16
-20
DEGREES
35
25
15
5
-5
-15
-25
-35

PLATE 32



SHIP TRACK-LINE, EXISTING CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 3

PLATE 33



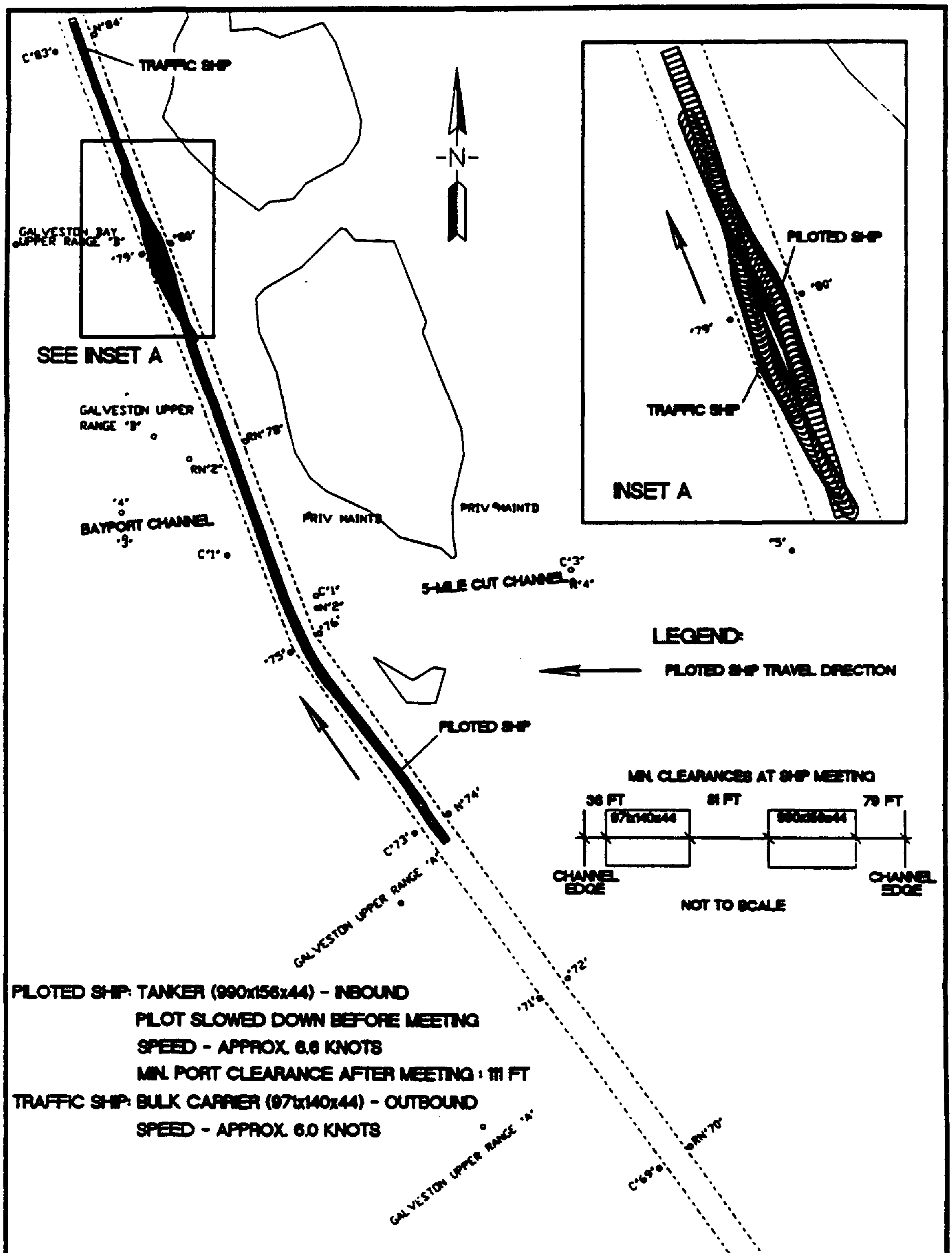
PILOTED SHIP: BULK CARRIER (775x106x39) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x39) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
EXISTING CHANNEL

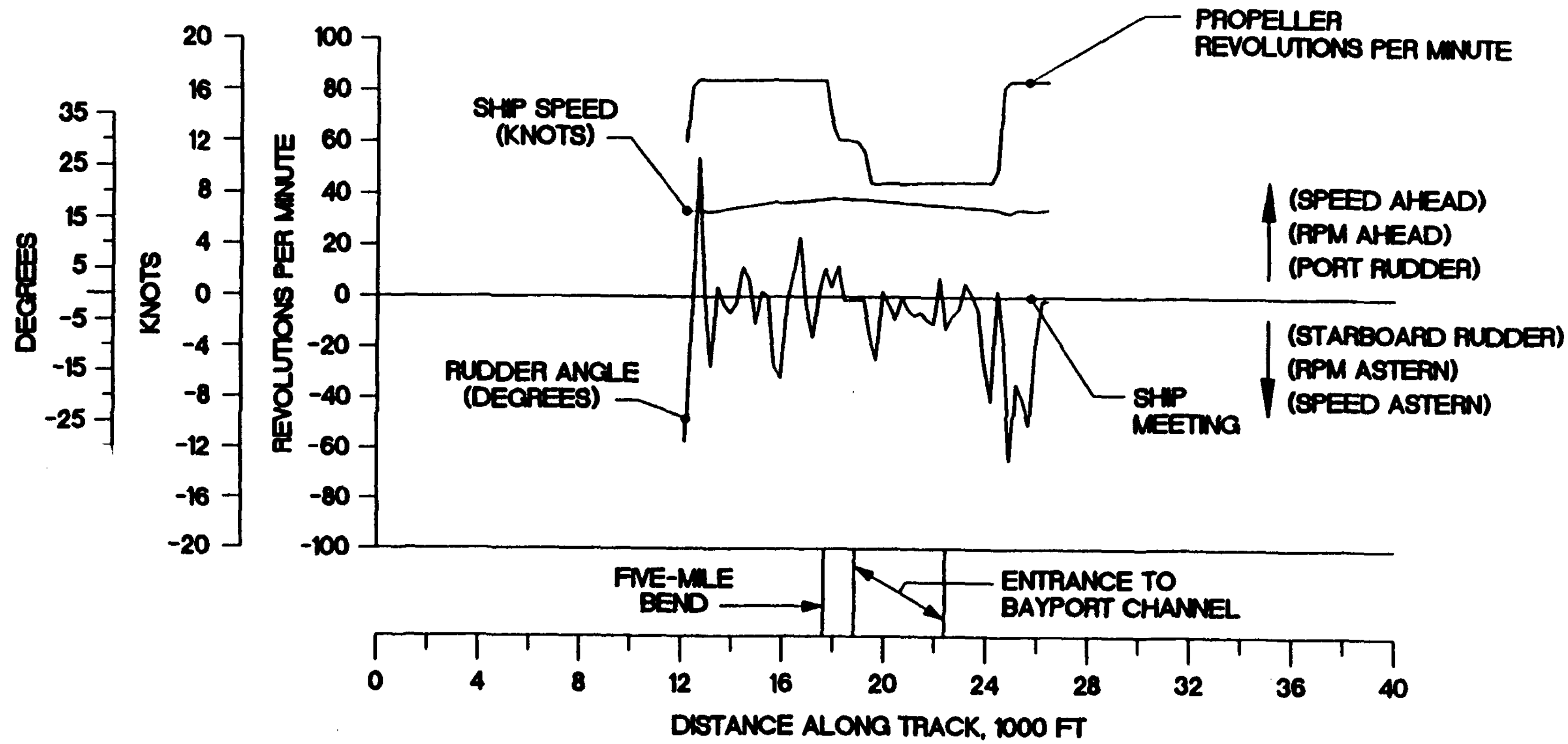
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 3

PLATE 34

530-ft Channel Simulator Tests

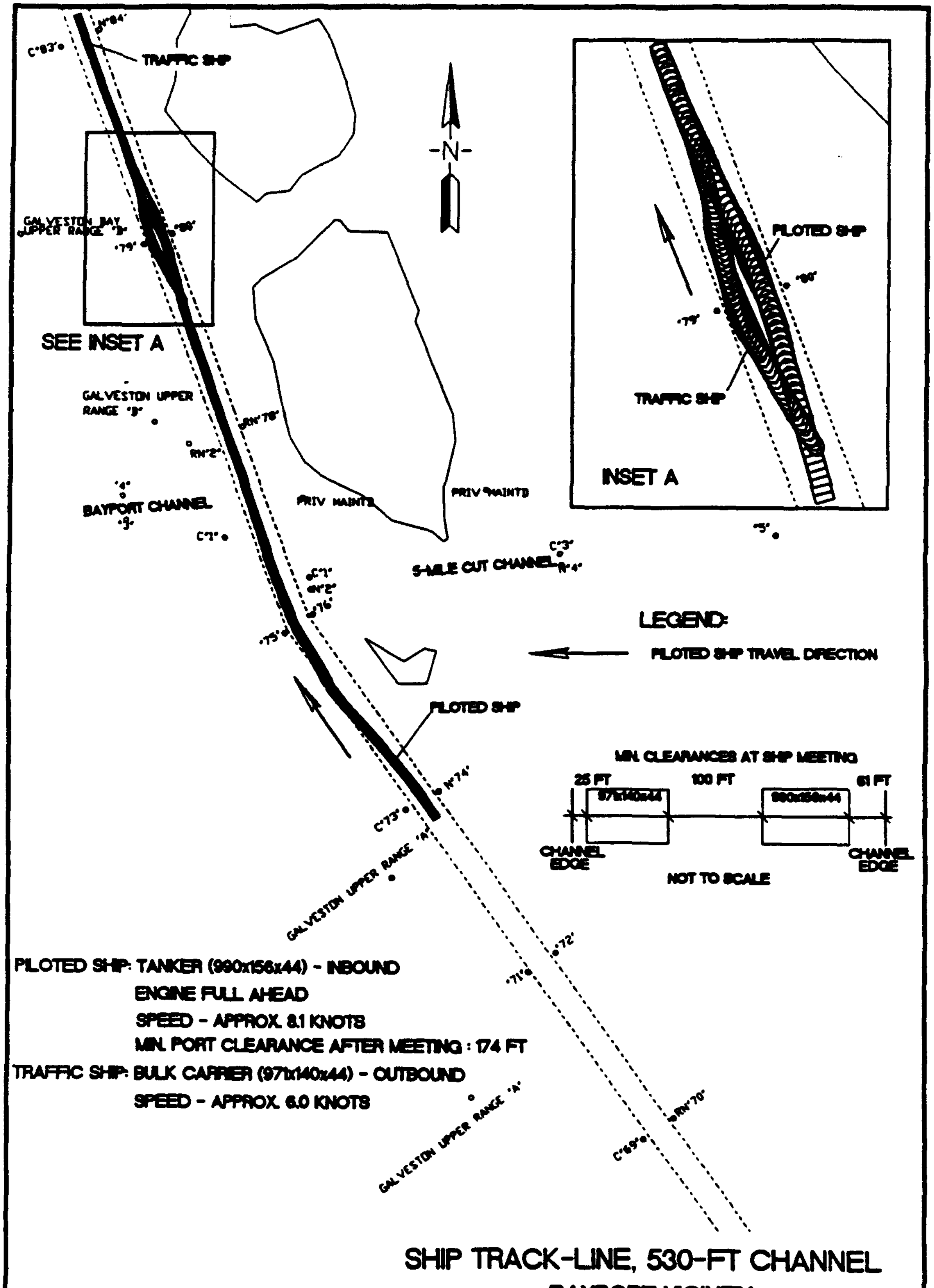


SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 1

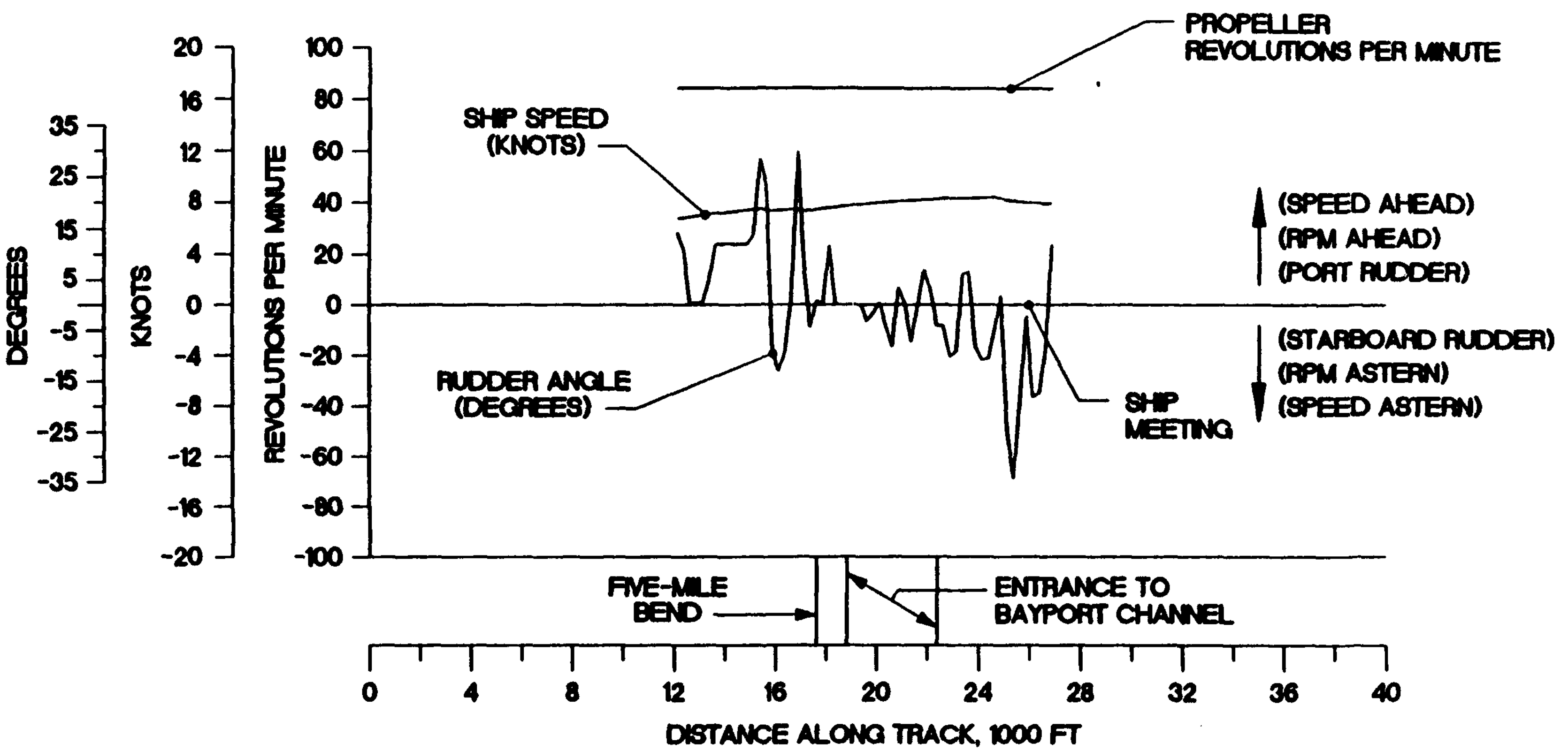


PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x44) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 1



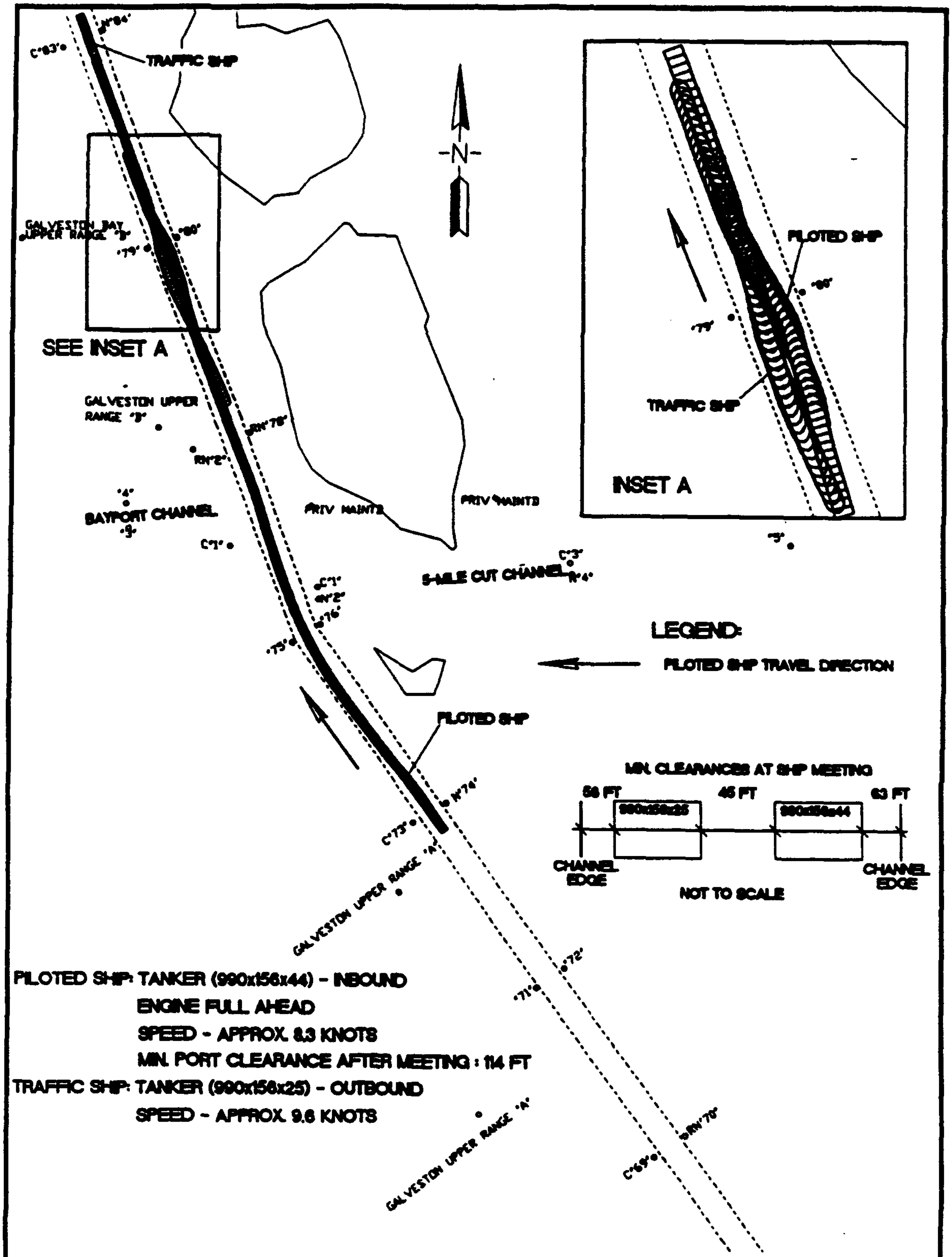
SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 1



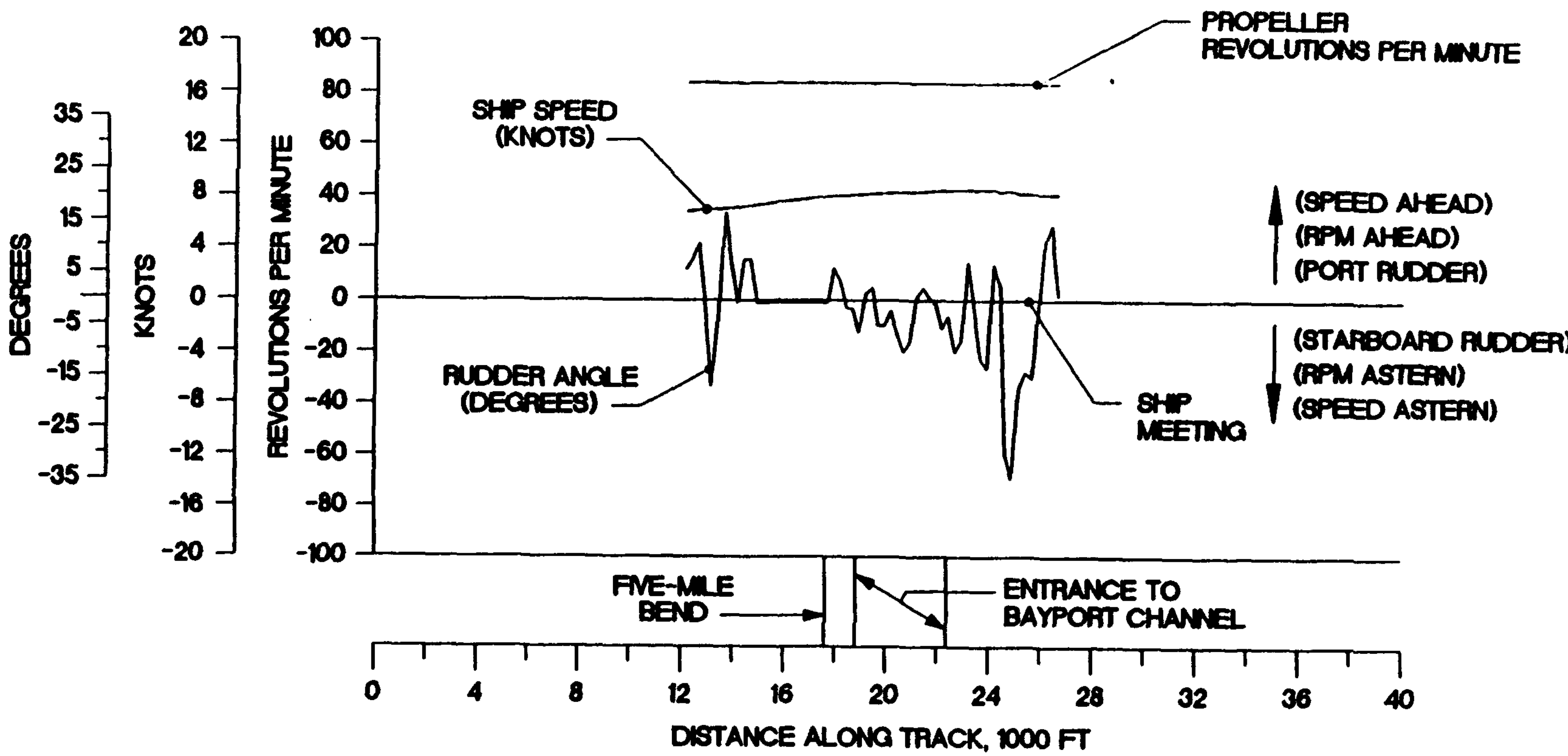
PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x44) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT Q, RUN 1

PLATE 38



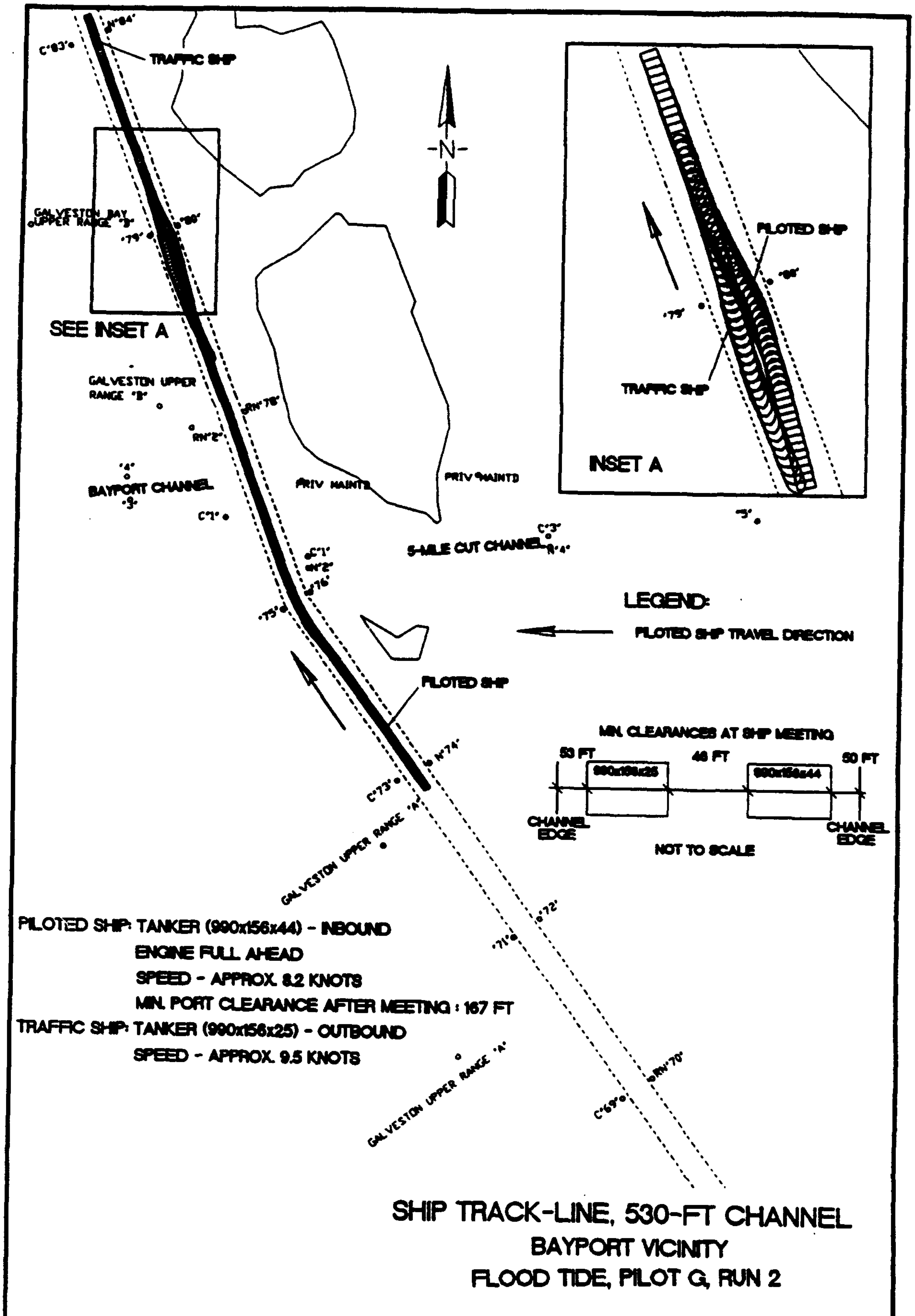
SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 2



PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: TANKER (990x156x25) - OUTBOUND

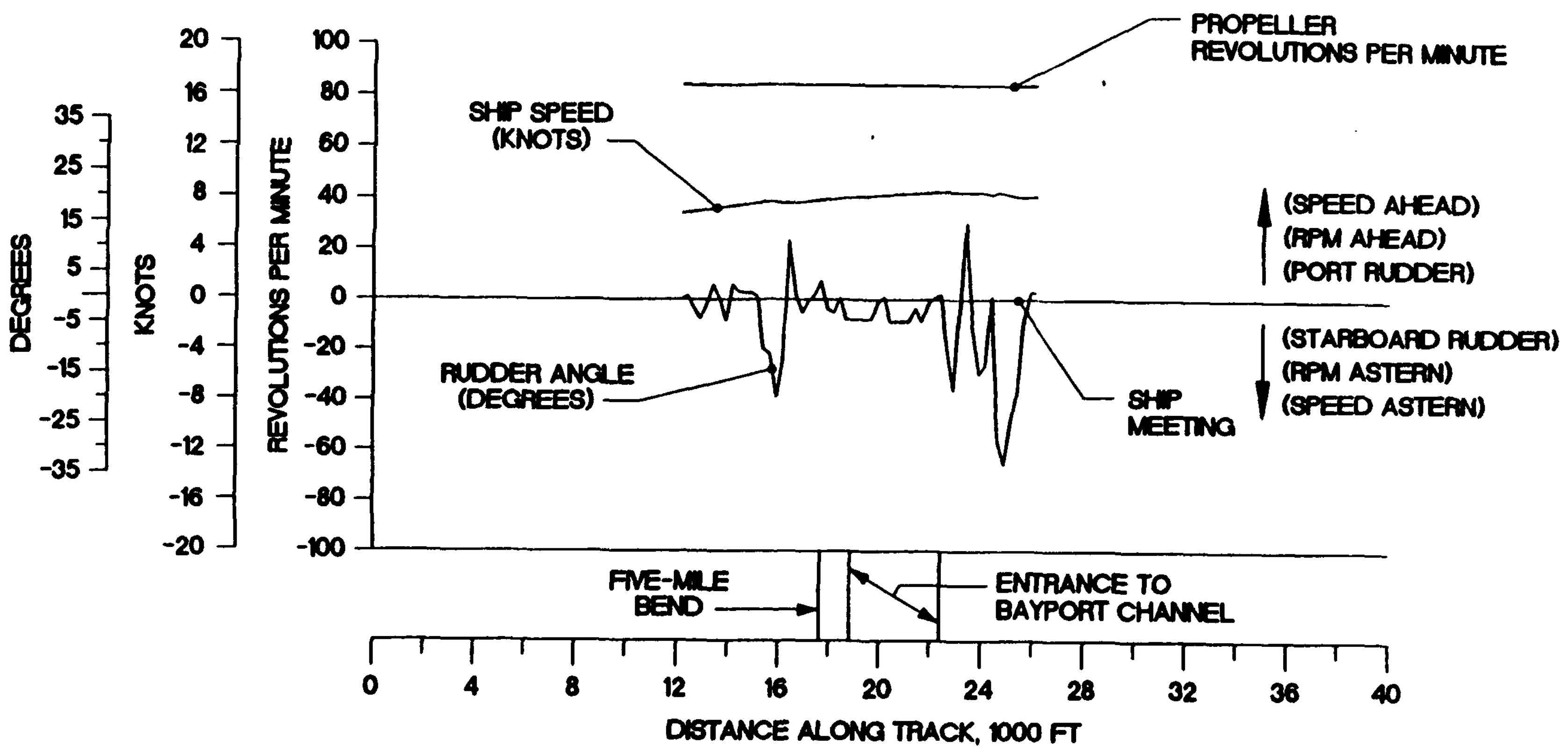
CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 2

PLATE 40



SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 2

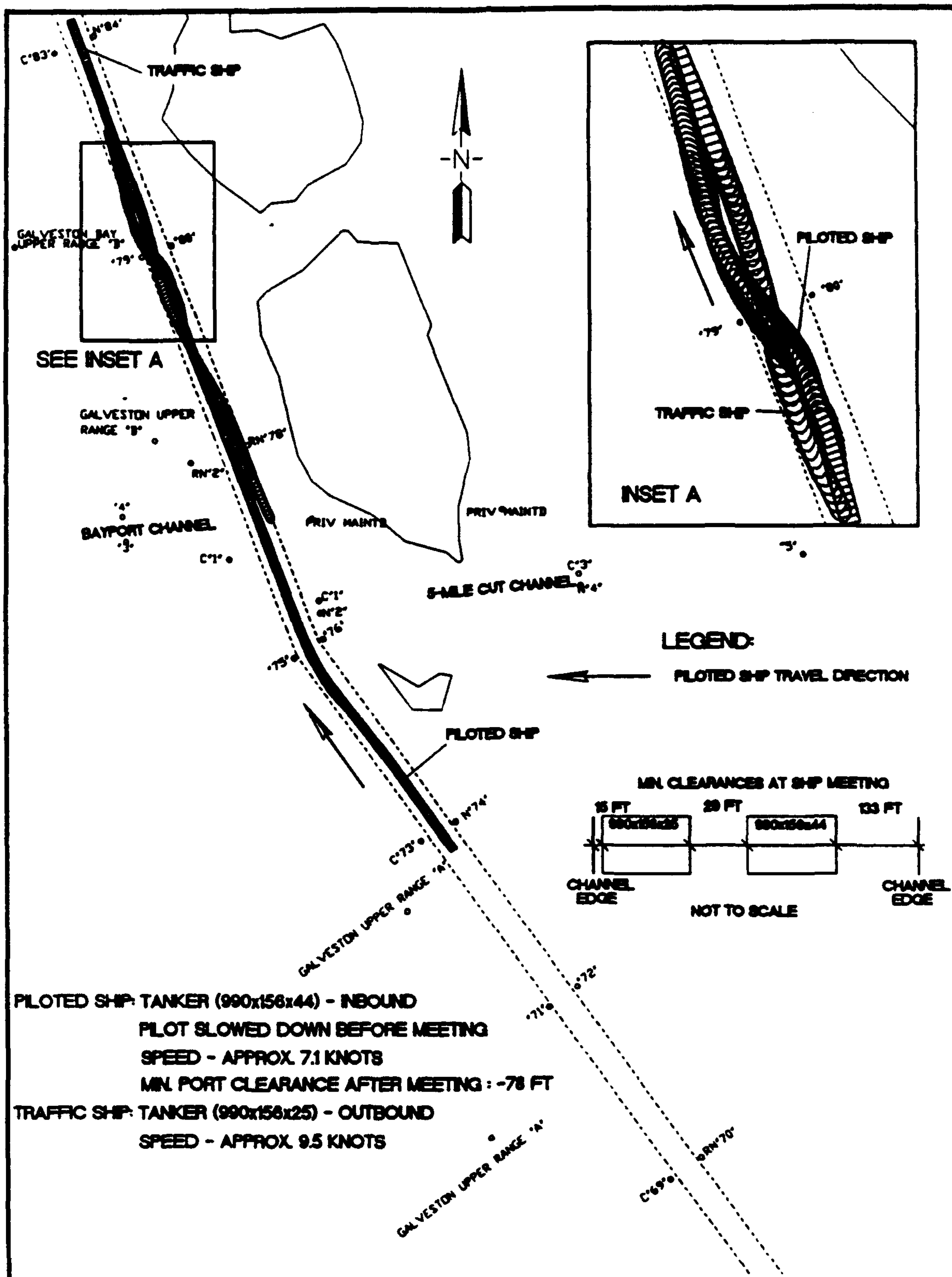
PLATE 41



CONTROL MEASURES
PILOTED SHIP
530 FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT Q, RUN 2

PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: TANKER (990x156x25) - OUTBOUND

PLATE 42



PILOTED SHIP: TANKER (990x156x44) - INBOUND
PILOT SLOWED DOWN BEFORE MEETING
SPEED - APPROX. 7.1 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : -78 FT
TRAFFIC SHIP: TANKER (990x156x25) - OUTBOUND
SPEED - APPROX. 9.5 KNOTS

SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 1

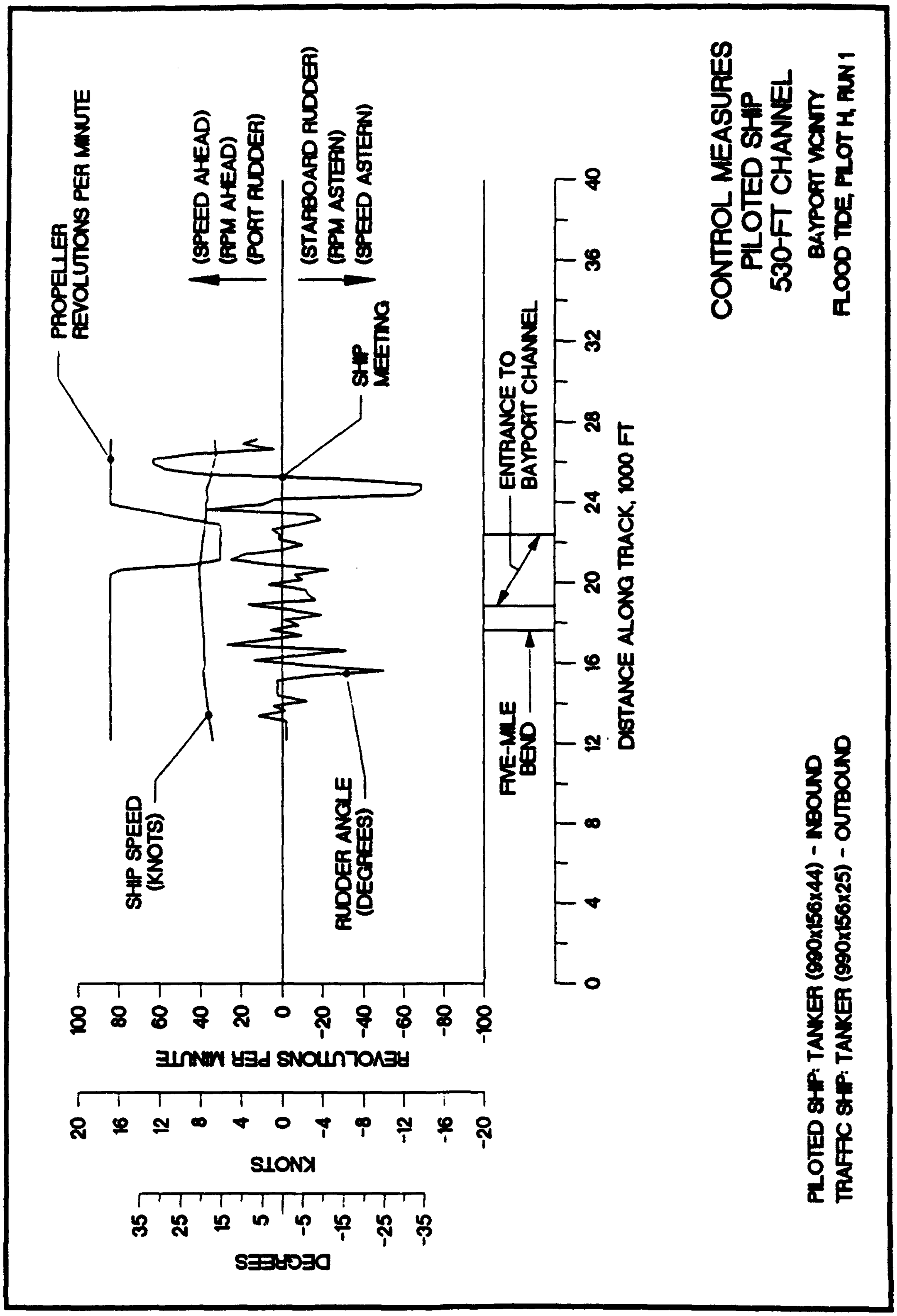
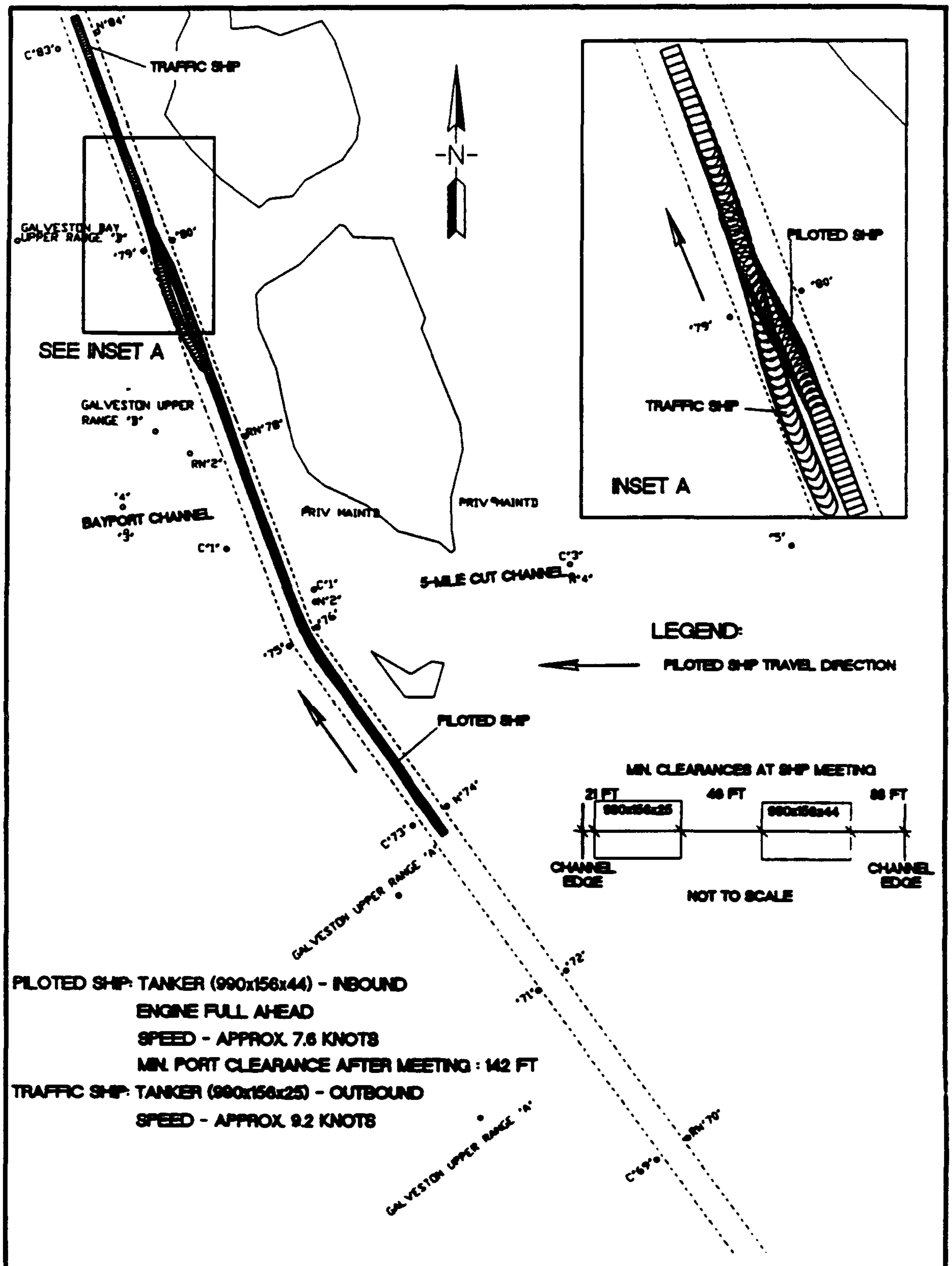
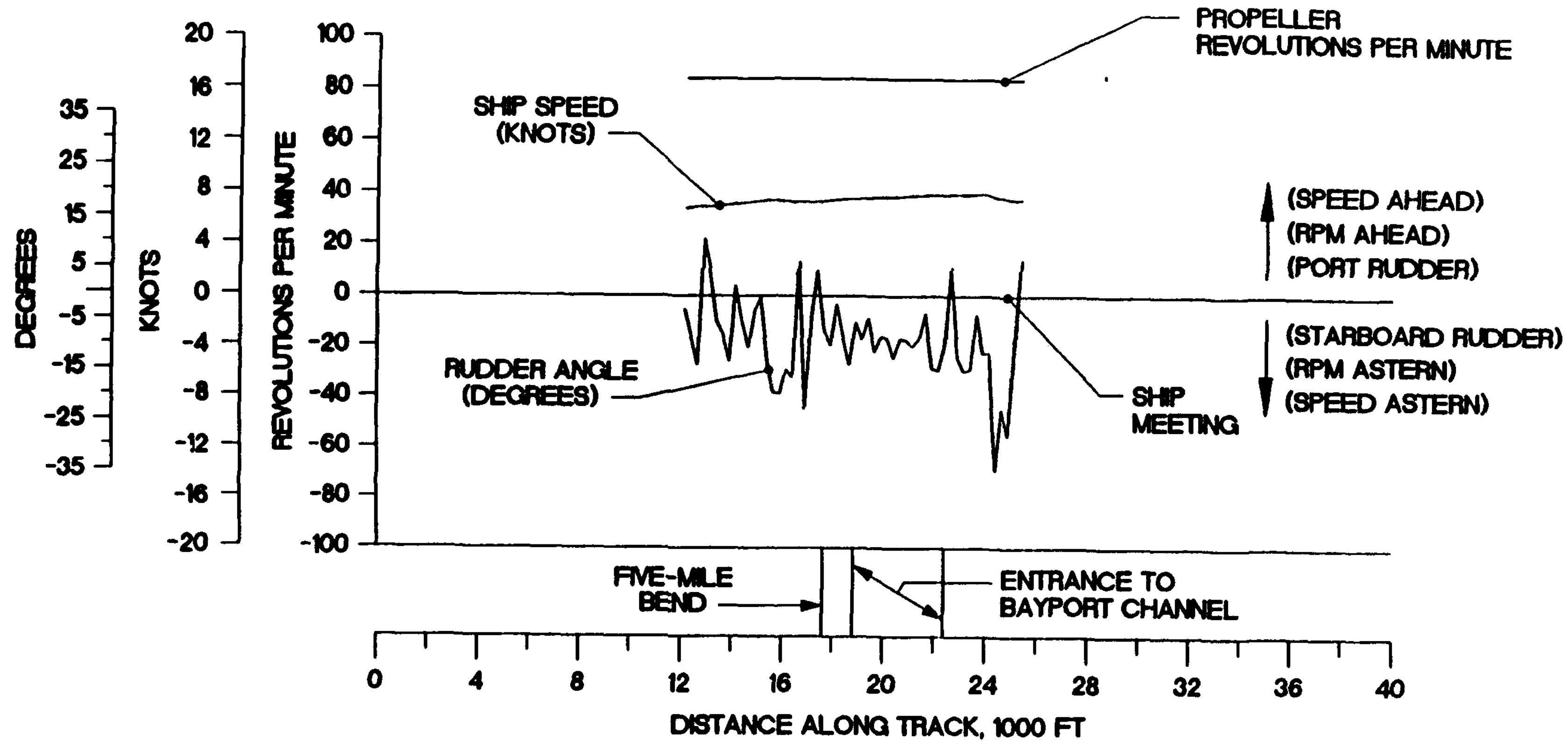

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 1
PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: TANKER (990x156x25) - OUTBOUND
PROPELLER REVOLUTIONS PER MINUTE
SHIP SPEED (KNOTS)
RUDDER ANGLE (DEGREES)
SHIP MEETING
(SPEED AHEAD)
(RPM AHEAD)
(PORT RUDDER)
(STARBOARD RUDDER)
(RPM ASTERN)
(SPEED ASTERN)
FIVE-MILE BEND
ENTRANCE TO BAYPORT CHANNEL
DISTANCE ALONG TRACK, 1000 FT
0
4
8
12
16
20
24
28
32
36
40
REVOLUTIONS PER MINUTE
100
80
60
40
20
0
-20
-40
-60
-80
-100
KNOTS
20
16
12
8
4
0
-4
-8
-12
-16
-20
DEGREES
35
25
15
5
-5
-15
-25
-35

PLATE 44

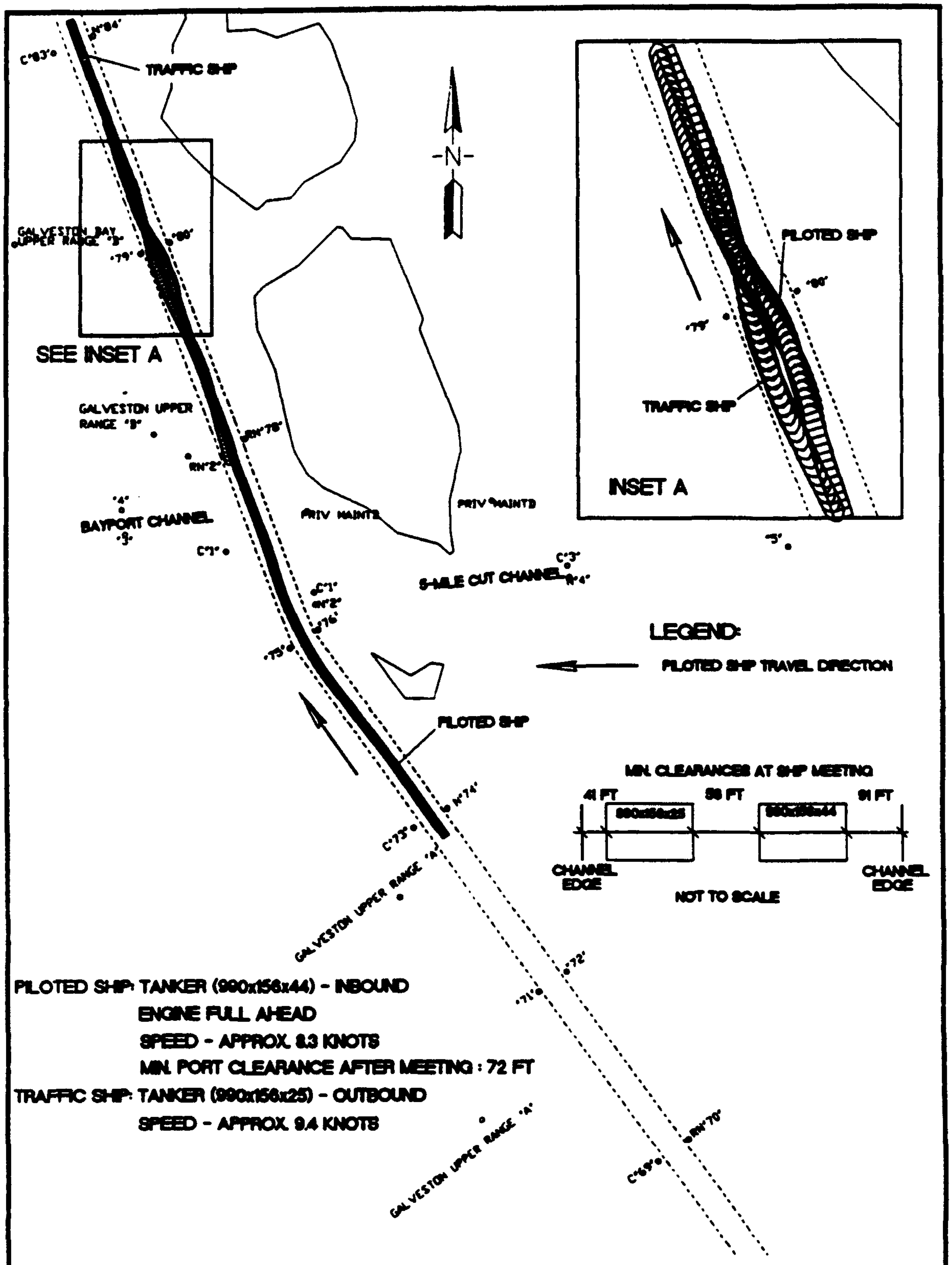


SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 2



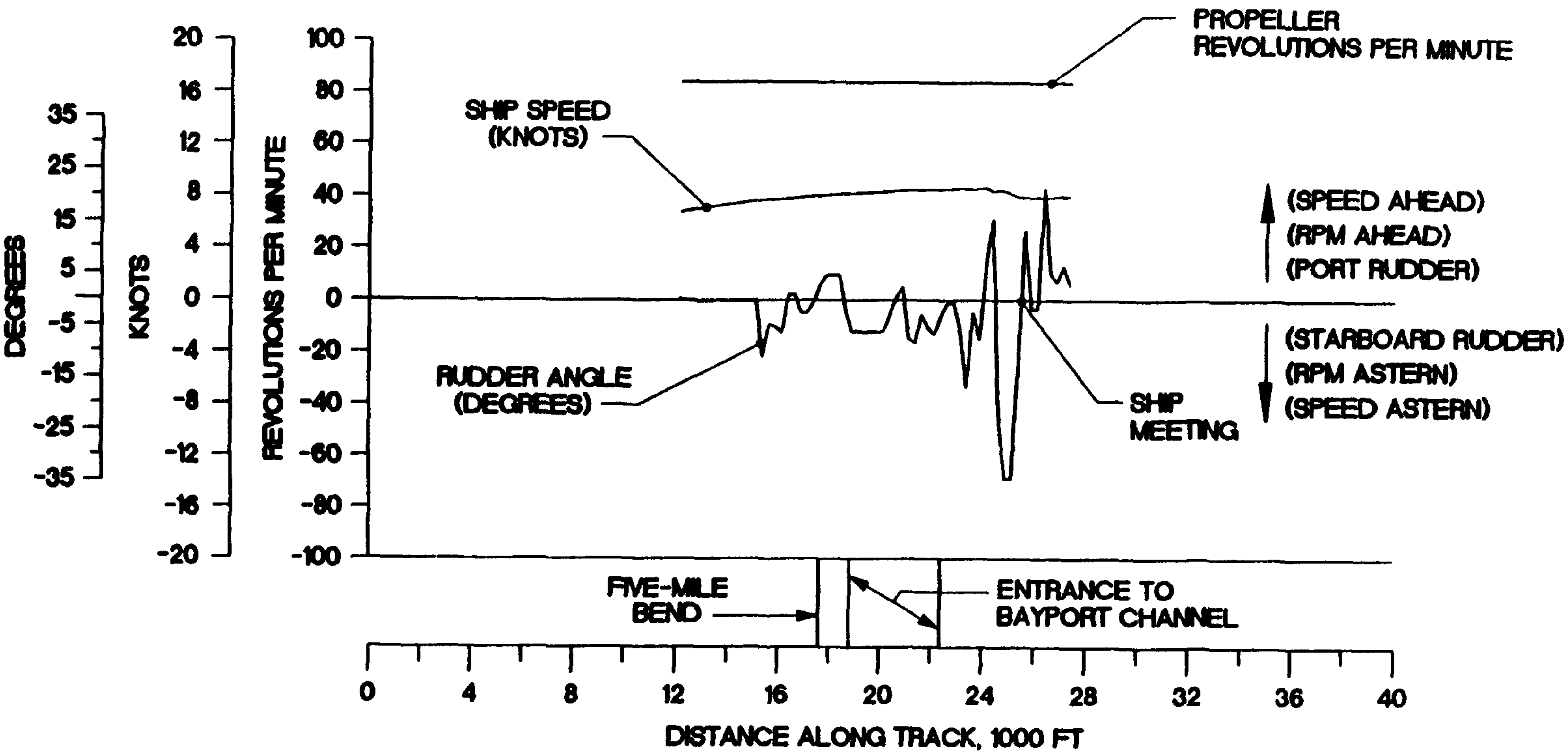
PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: TANKER (990x156x25) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
530 FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 2



SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 1

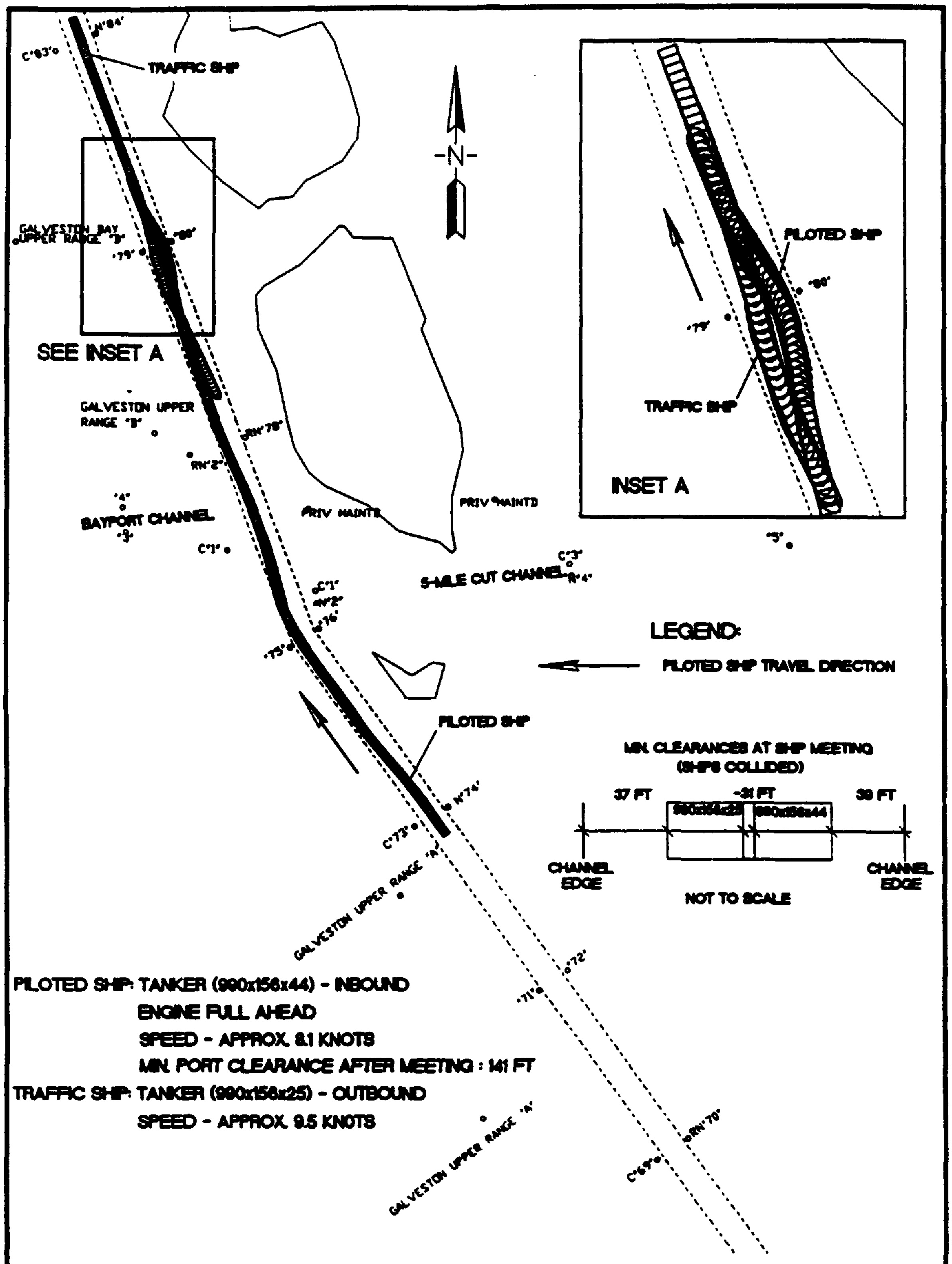
PLATE 47



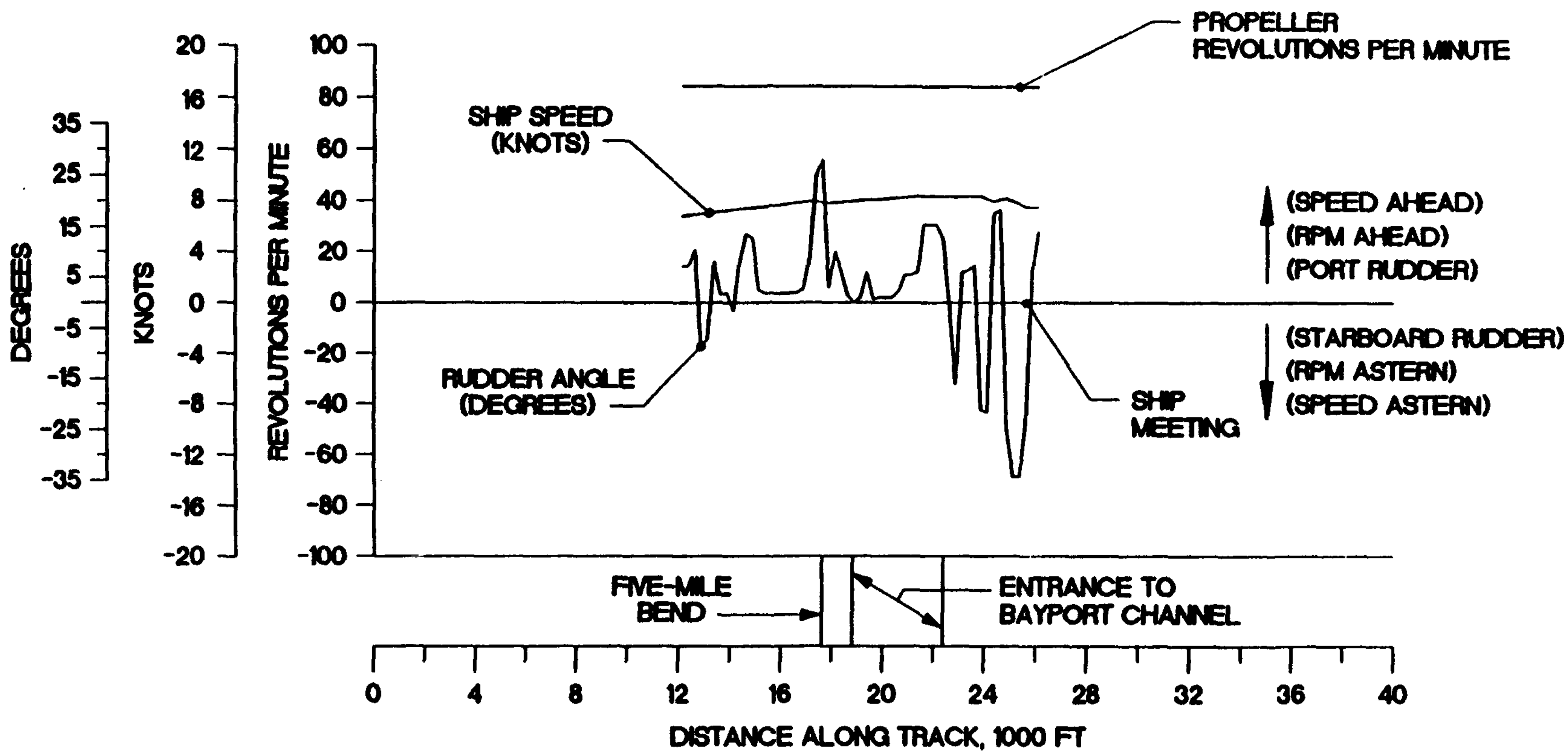
PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: TANKER (990x156x25) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 1

PLATE 48



SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 2

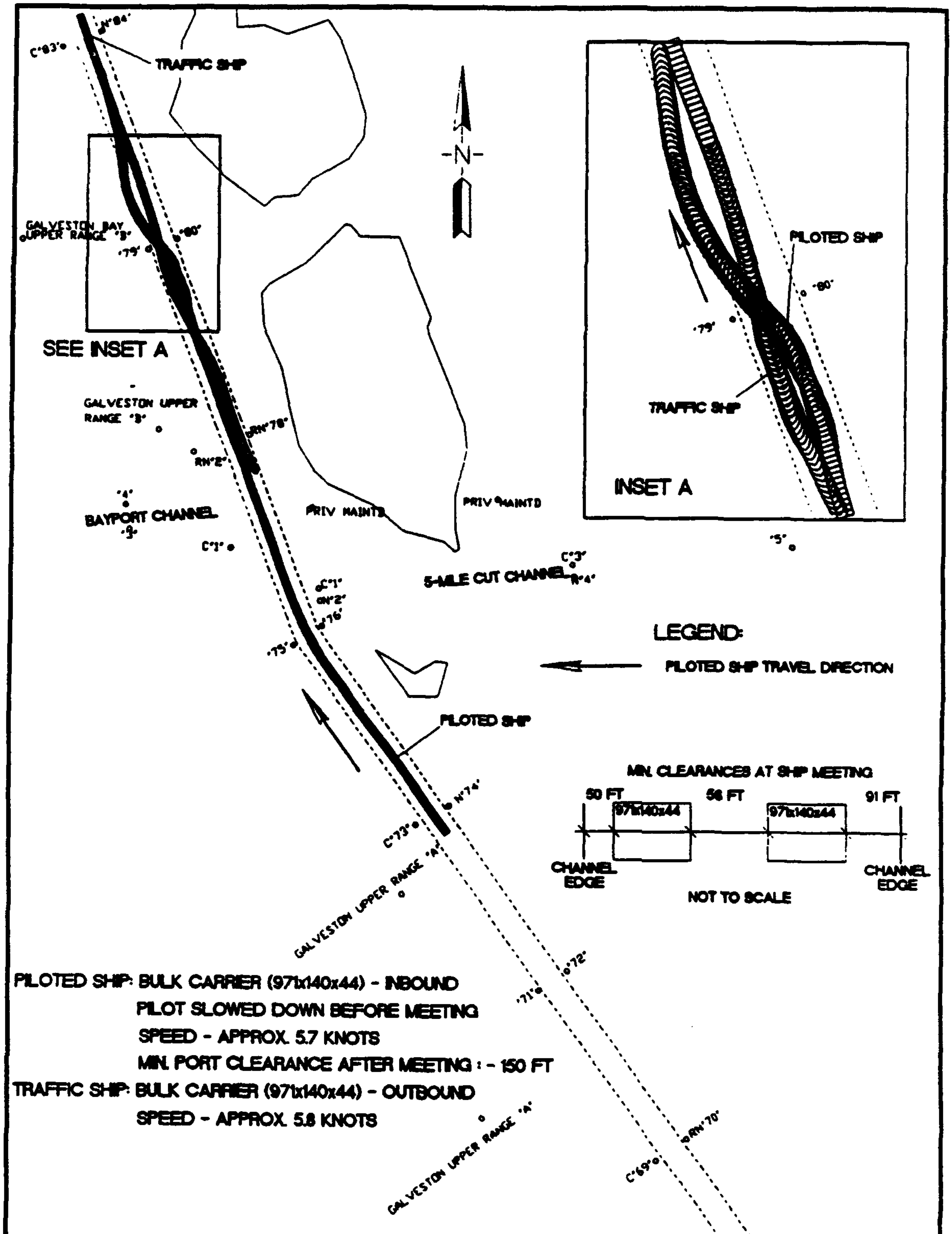


CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL

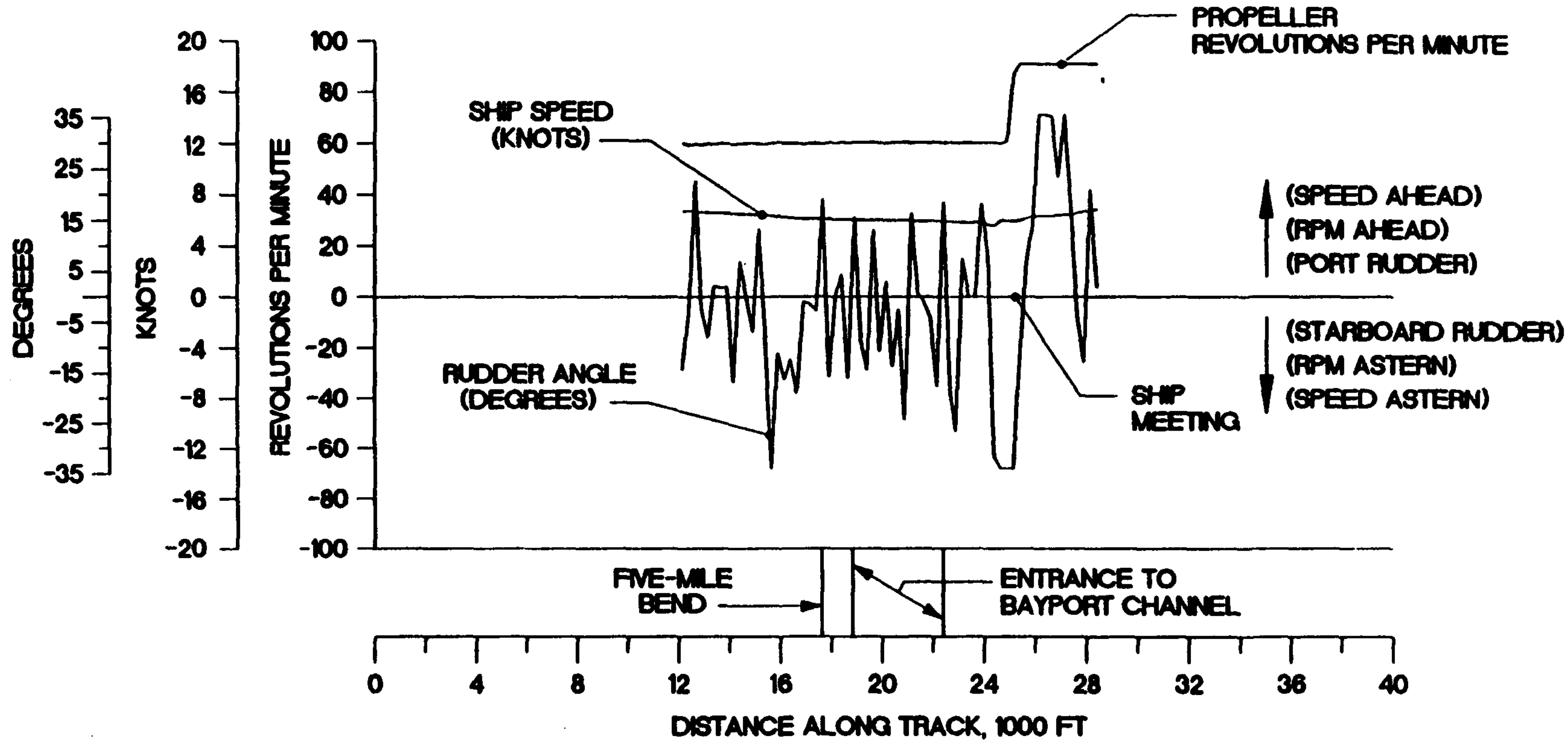
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 2

PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: TANKER (990x156x25) - OUTBOUND

PLATE 50



SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT K, RUN 1

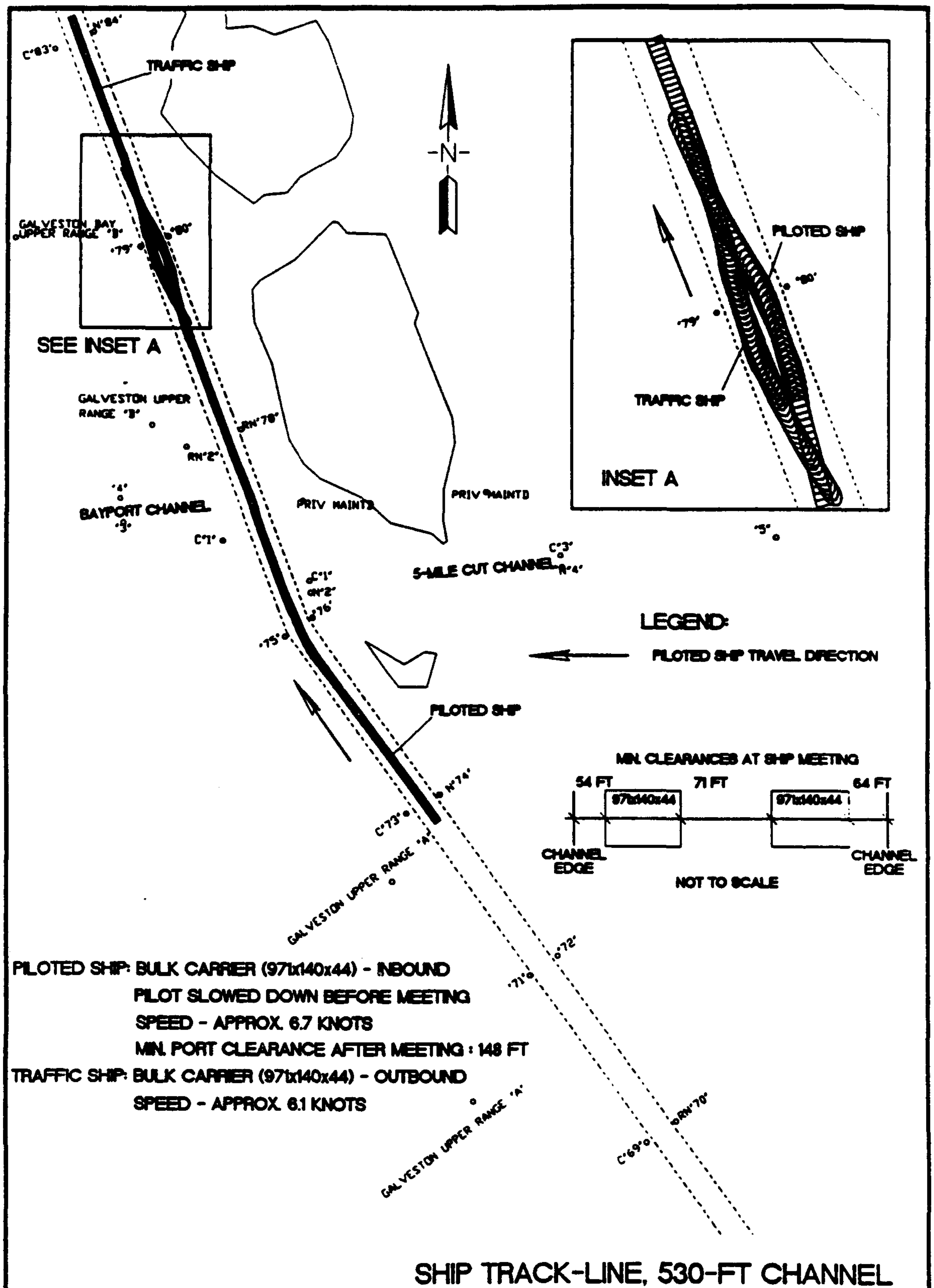


CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL

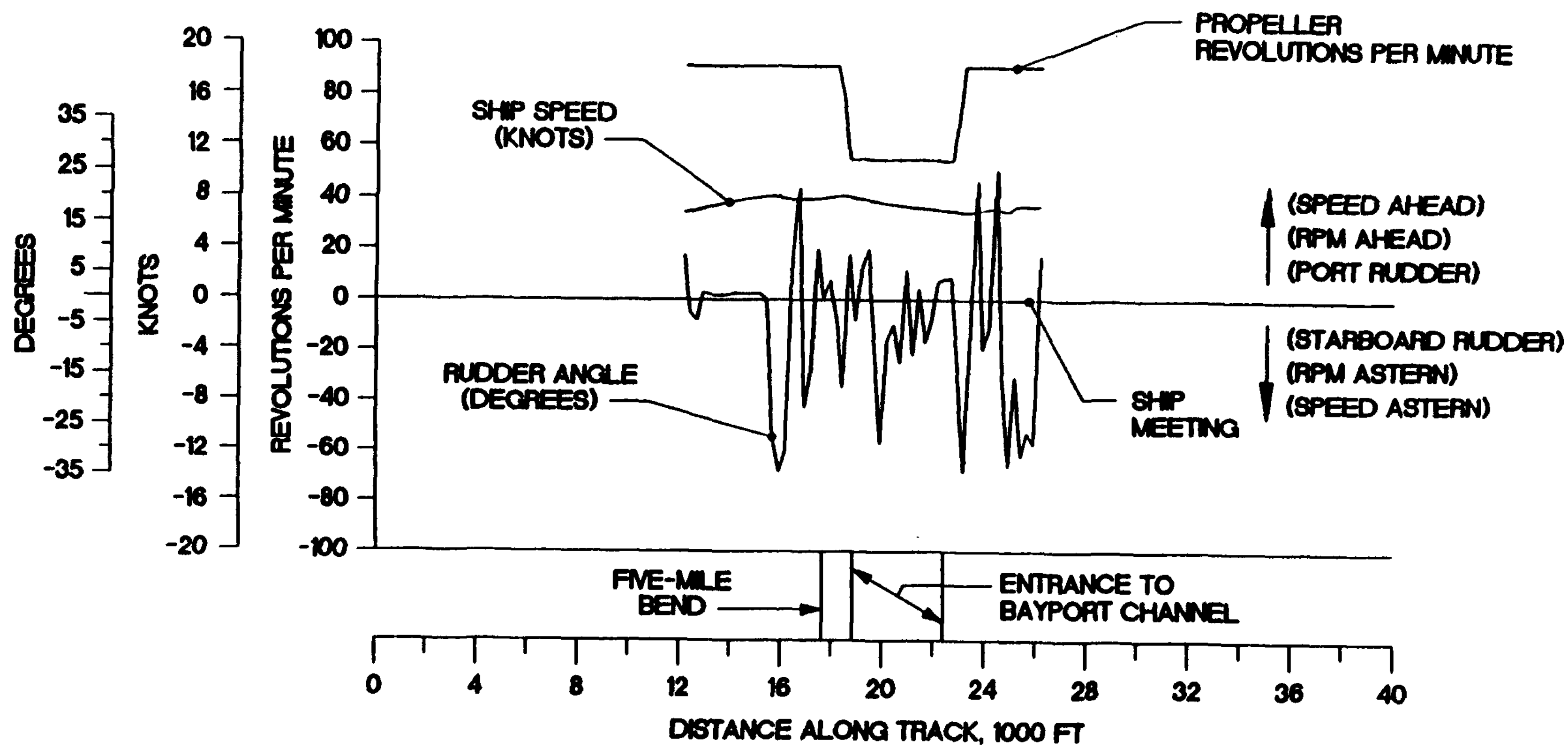
BAYPORT VICINITY
FLOOD TIDE, PILOT K, RUN 1

PILOTED SHIP: BULK CARRIER (971x140x44) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x44) - OUTBOUND

PLATE 52



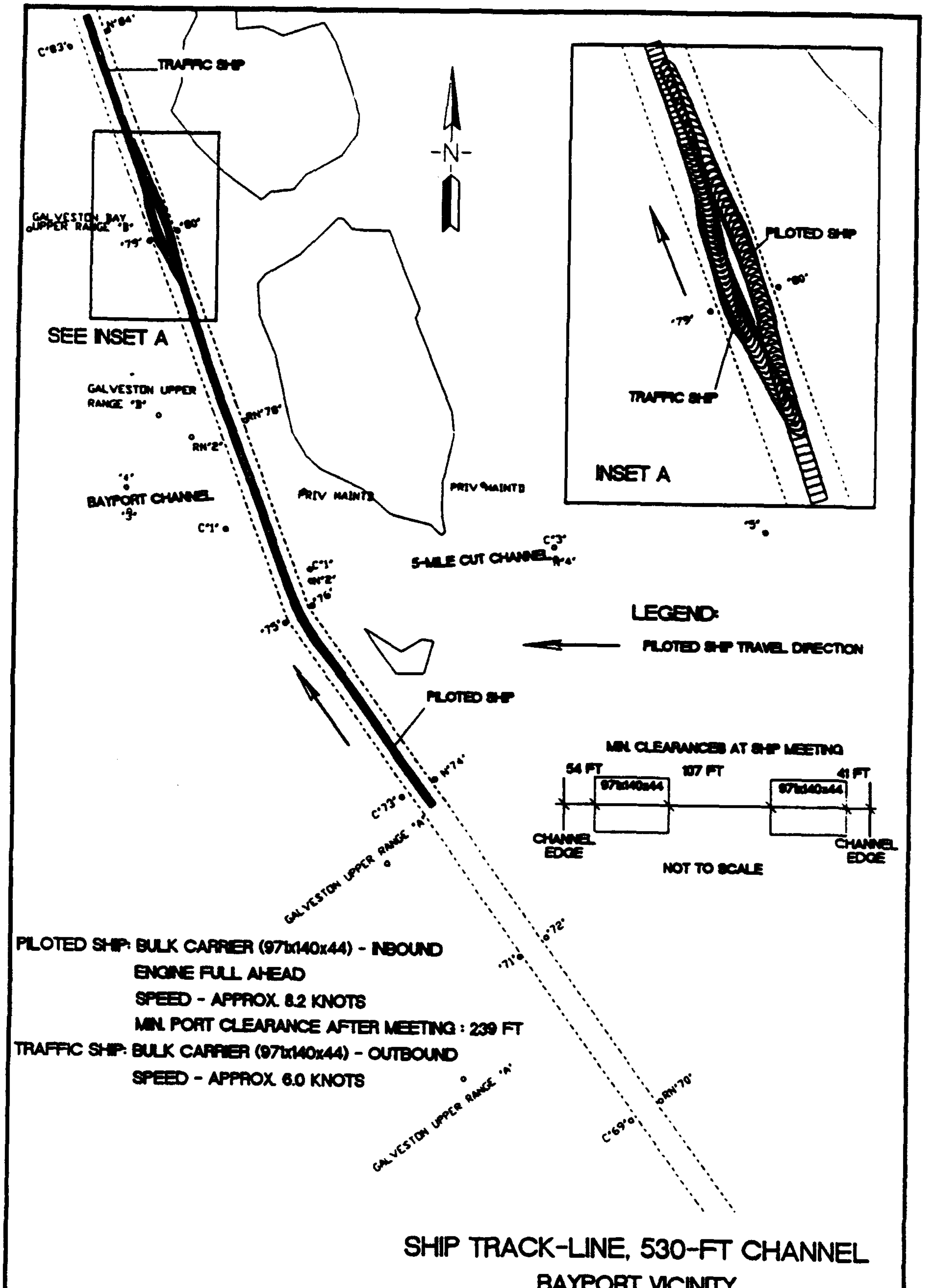
SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT K, RUN 2



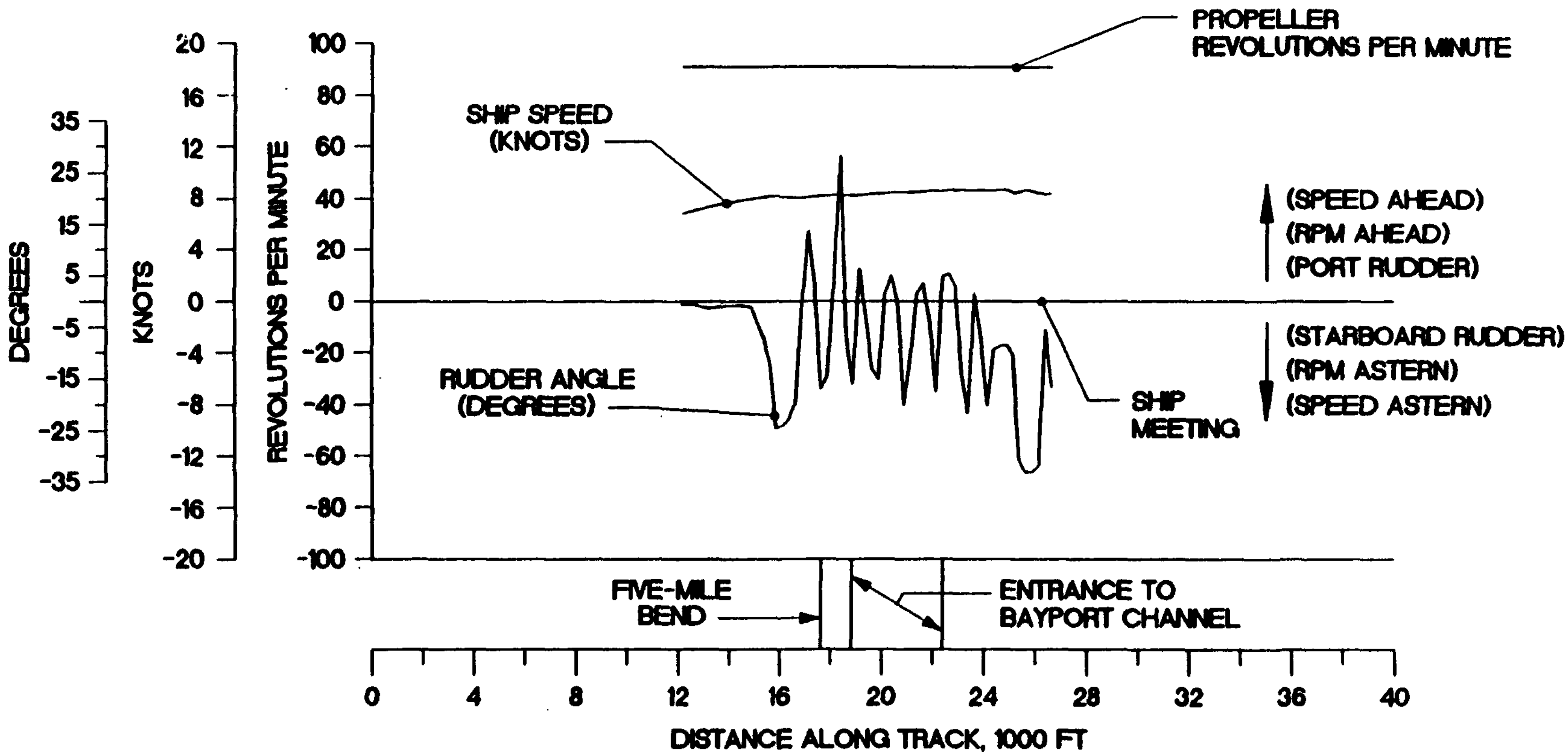
PILOTED SHIP: BULK CARRIER (971x140x44) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x44) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT K, RUN 2

PLATE 54



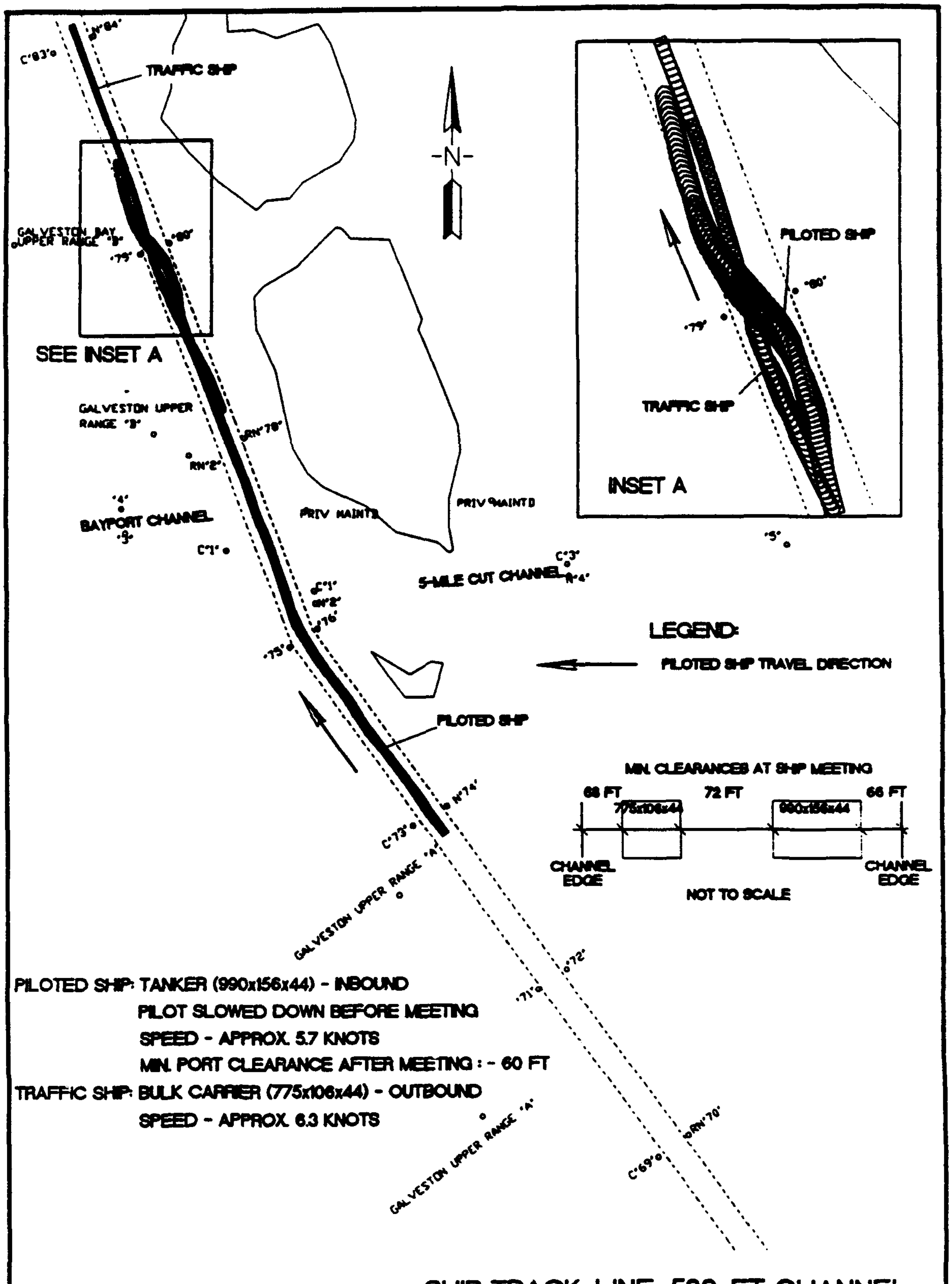
SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT L, RUN 1



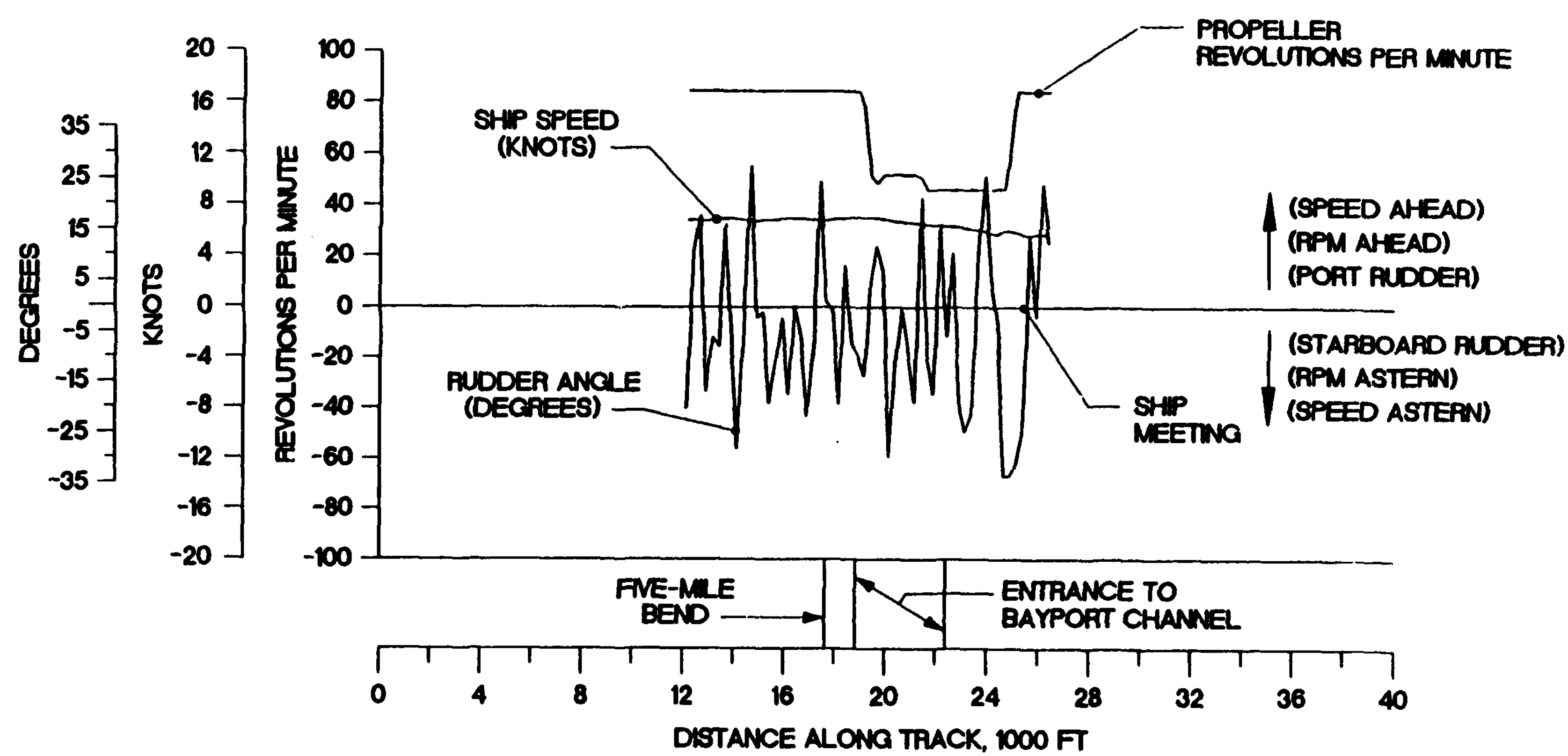
PILOTED SHIP: BULK CARRIER (971x140x44) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x44) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT L, RUN 1

PLATE 56



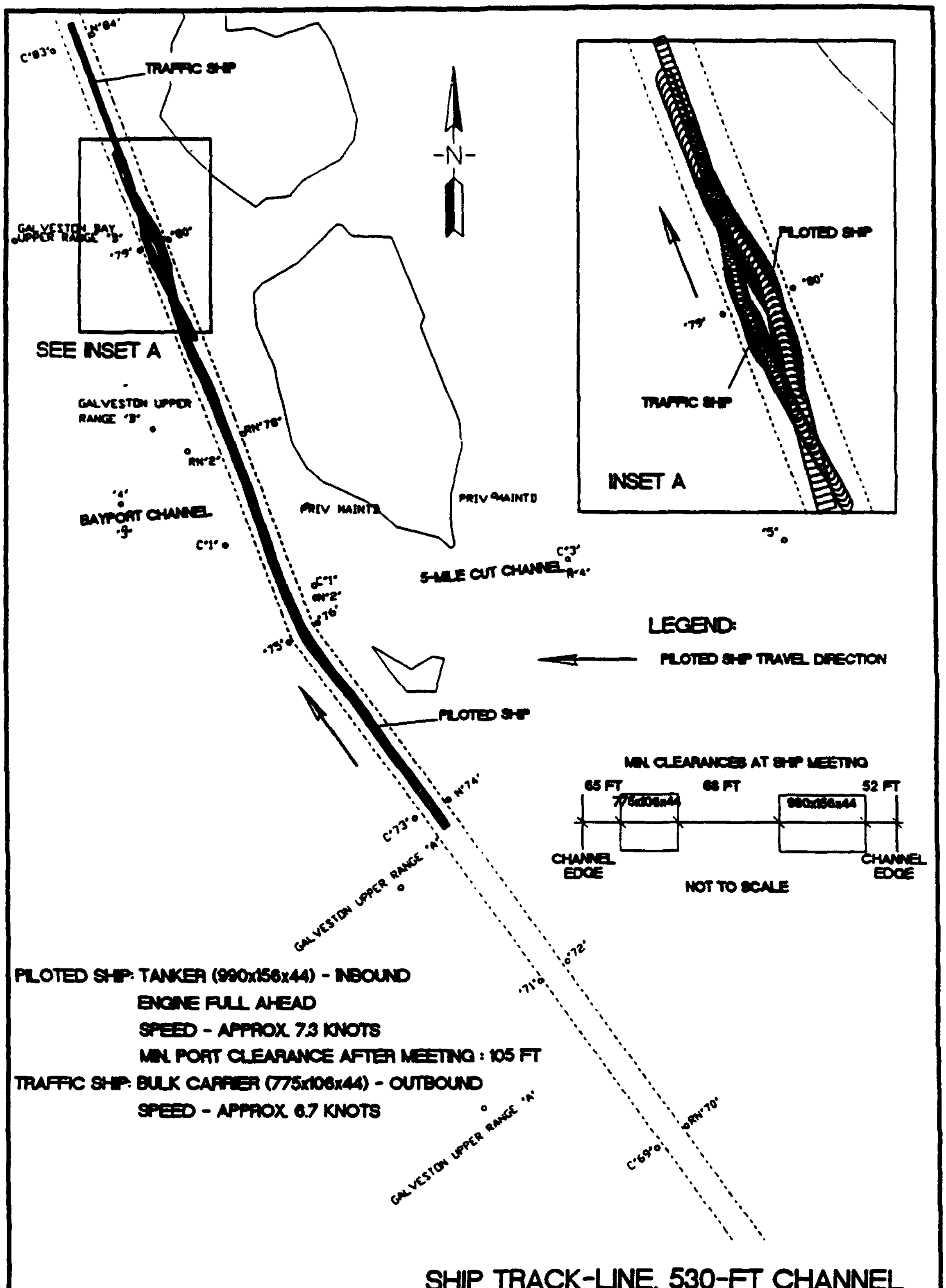
SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT K



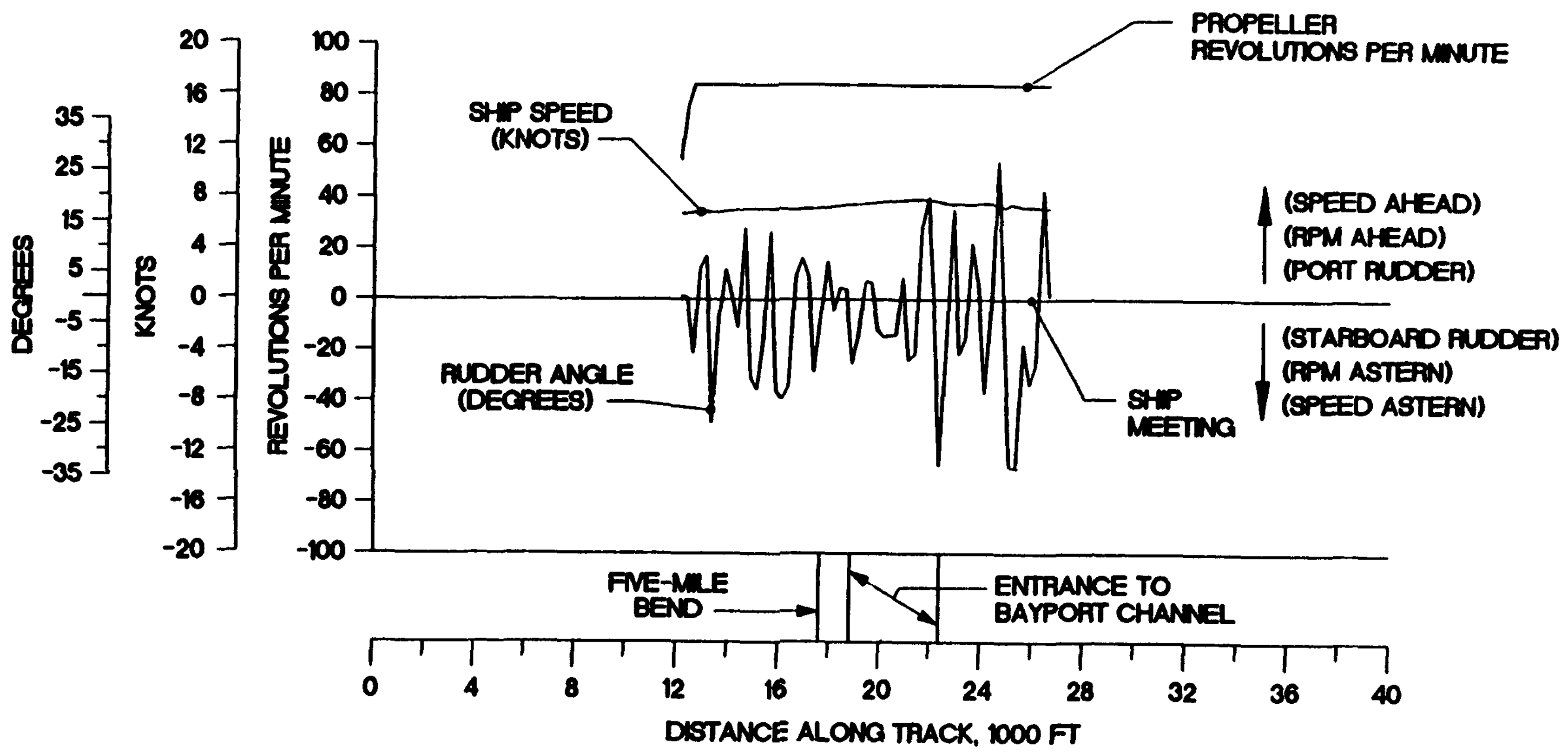
PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x44) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT K

PLATE 58

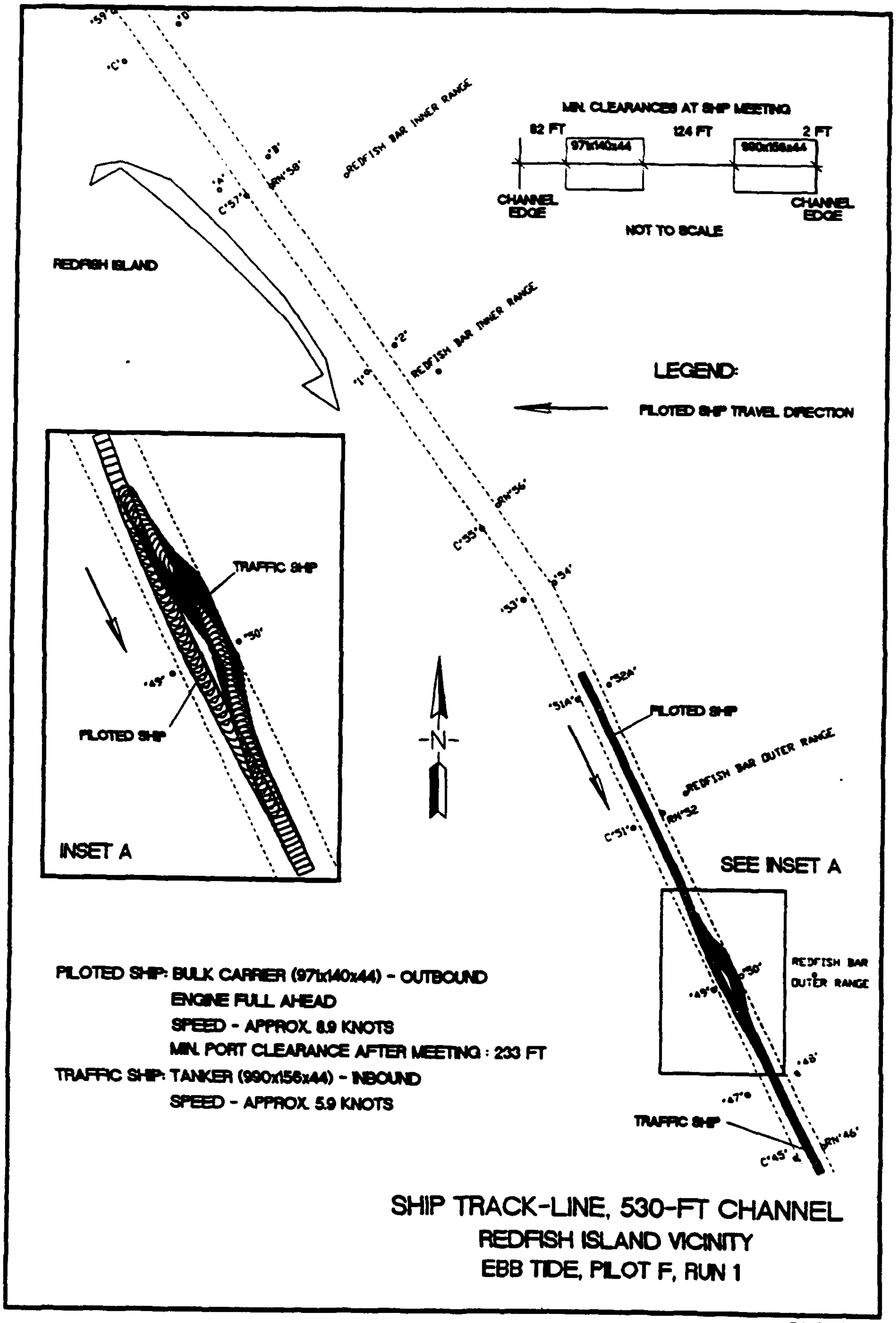


SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT L, RUN 2



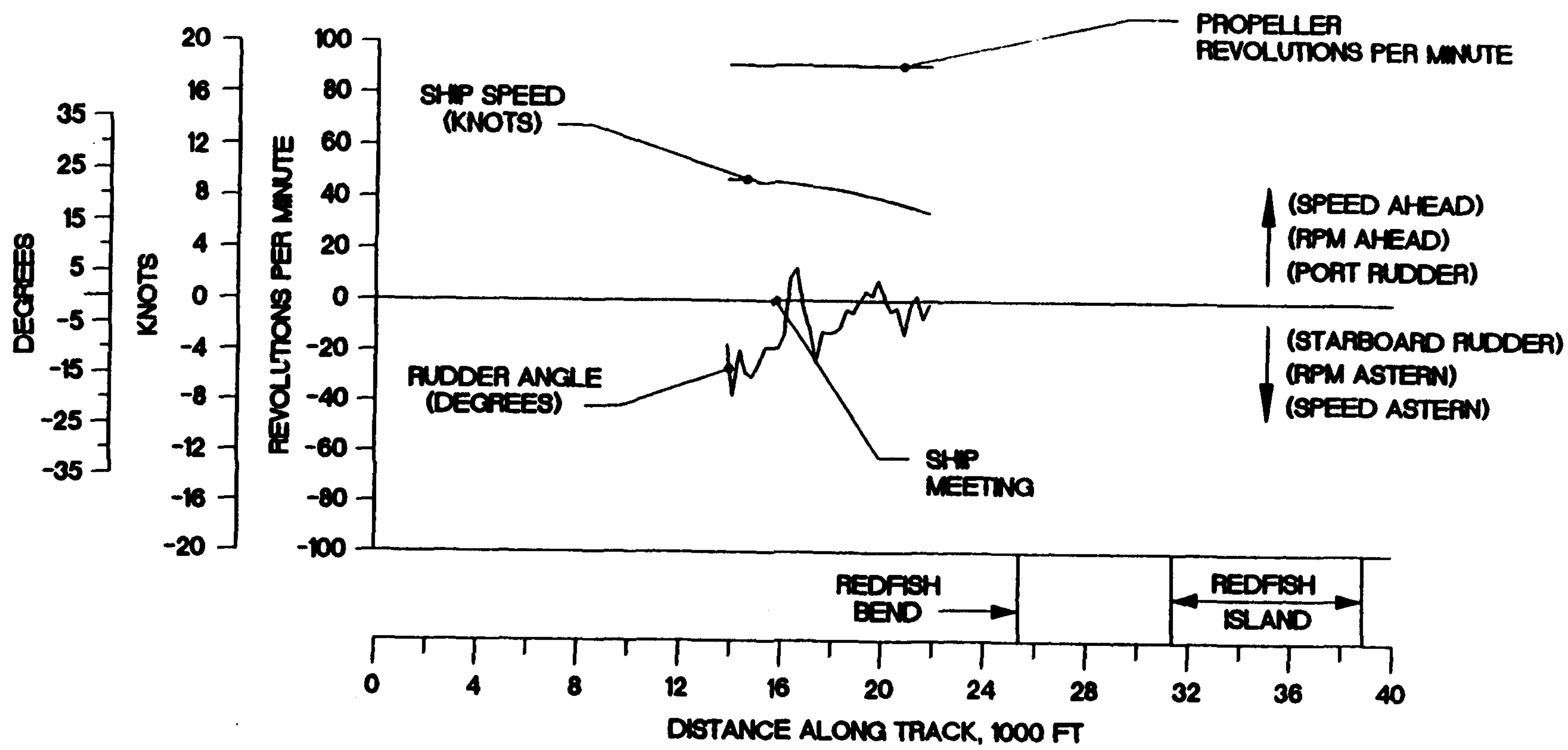
PILOTED SHIP: TANKER (990x156x44) - INBOUND
TRAFFIC SHIP: BULK CARRIER (775x106x44) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT L, RUN 2



PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
ENGINE FULL AHEAD
SPEED - APPROX. 8.9 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : 233 FT
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND
SPEED - APPROX. 5.9 KNOTS

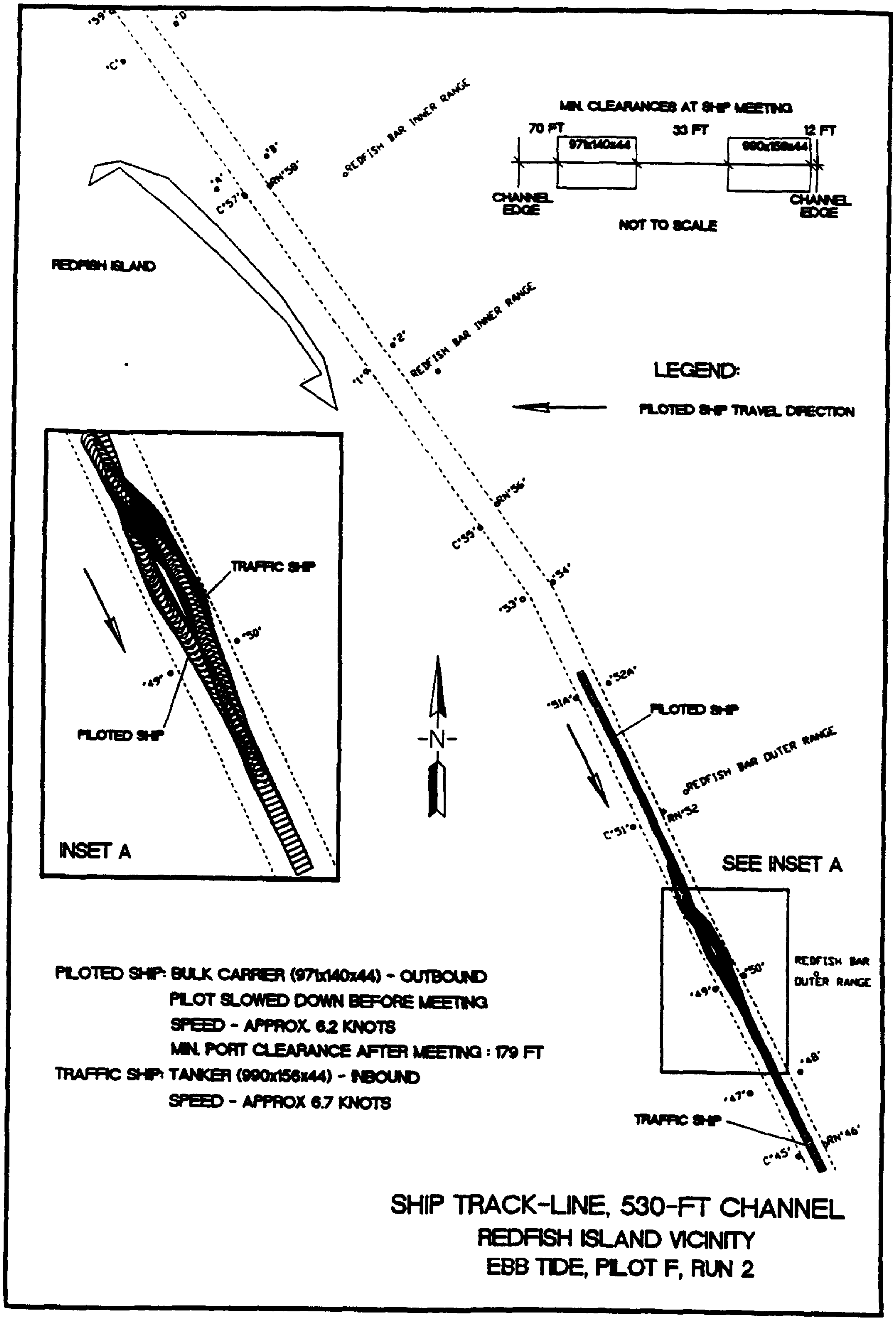
SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 1



PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND

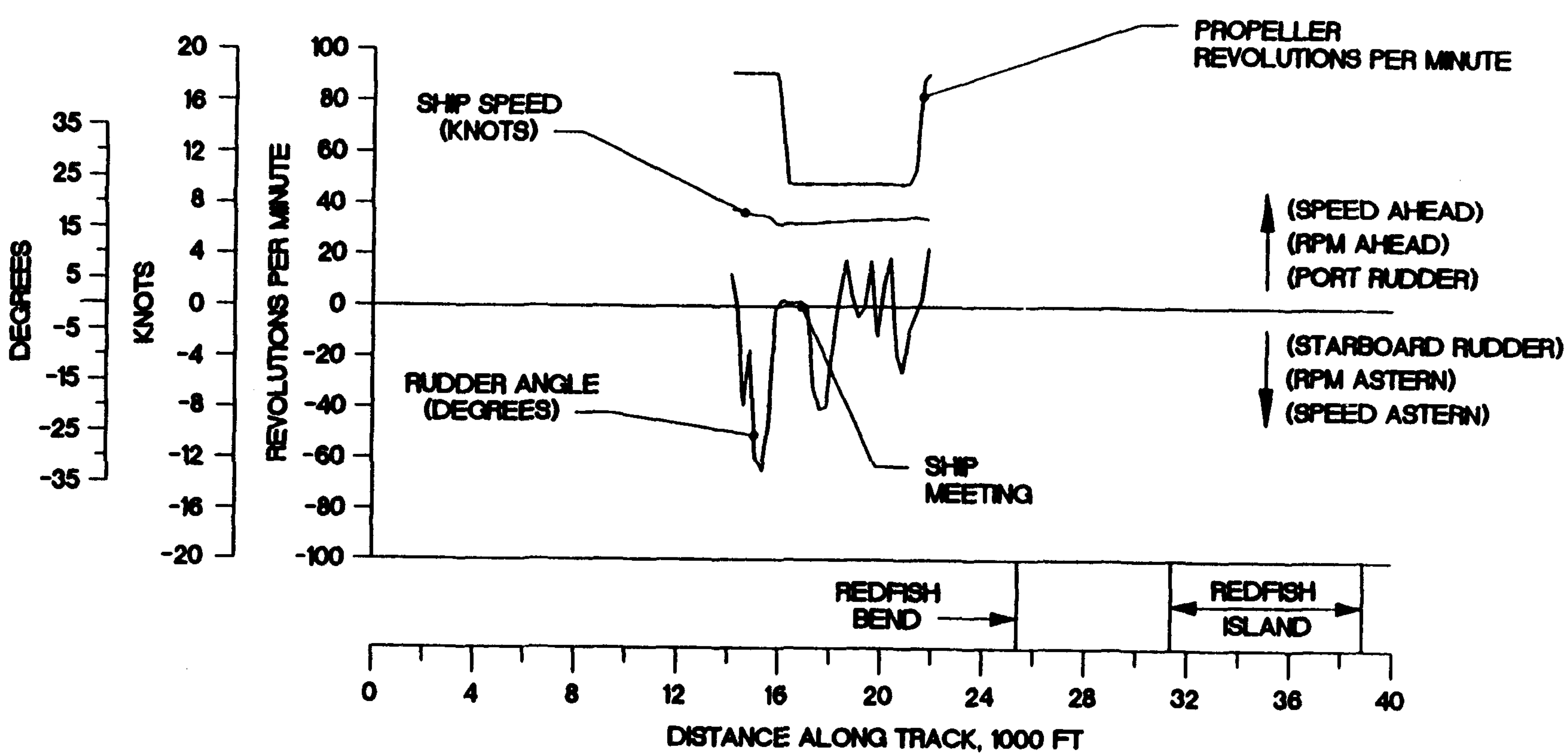
CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 1

PLATE 62



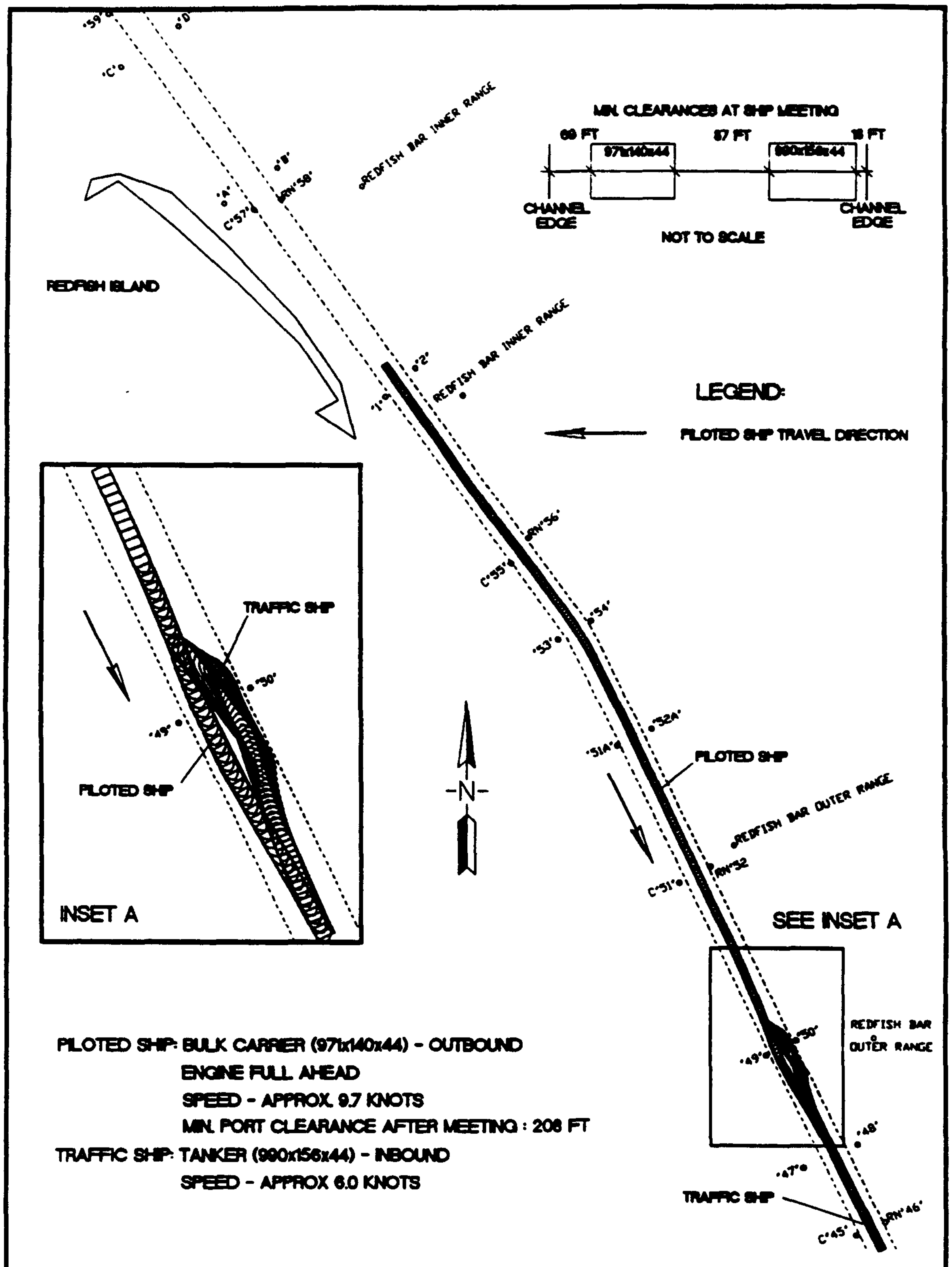
SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 2

PLATE 63

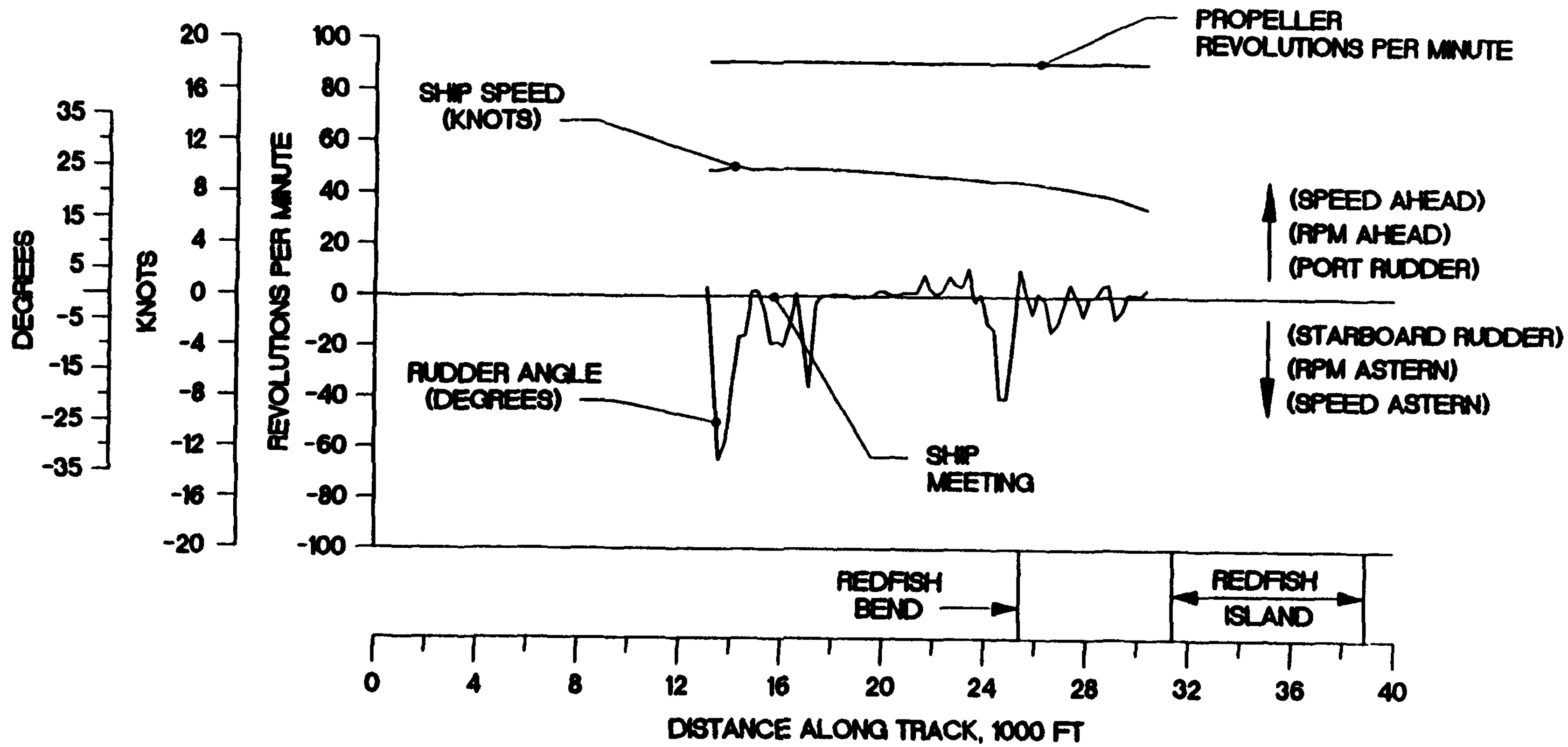


CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 2

PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND



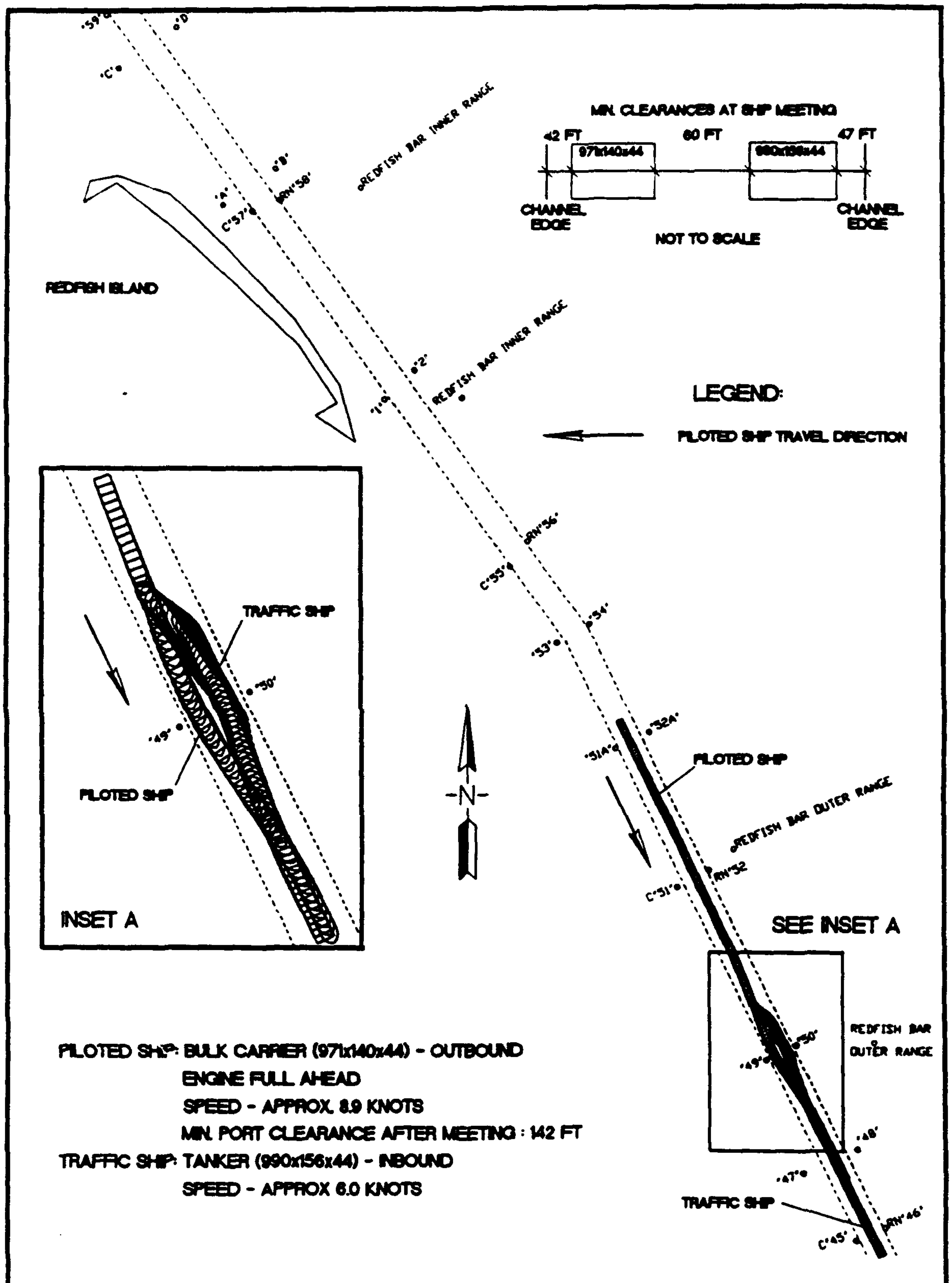
SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT G, RUN 1



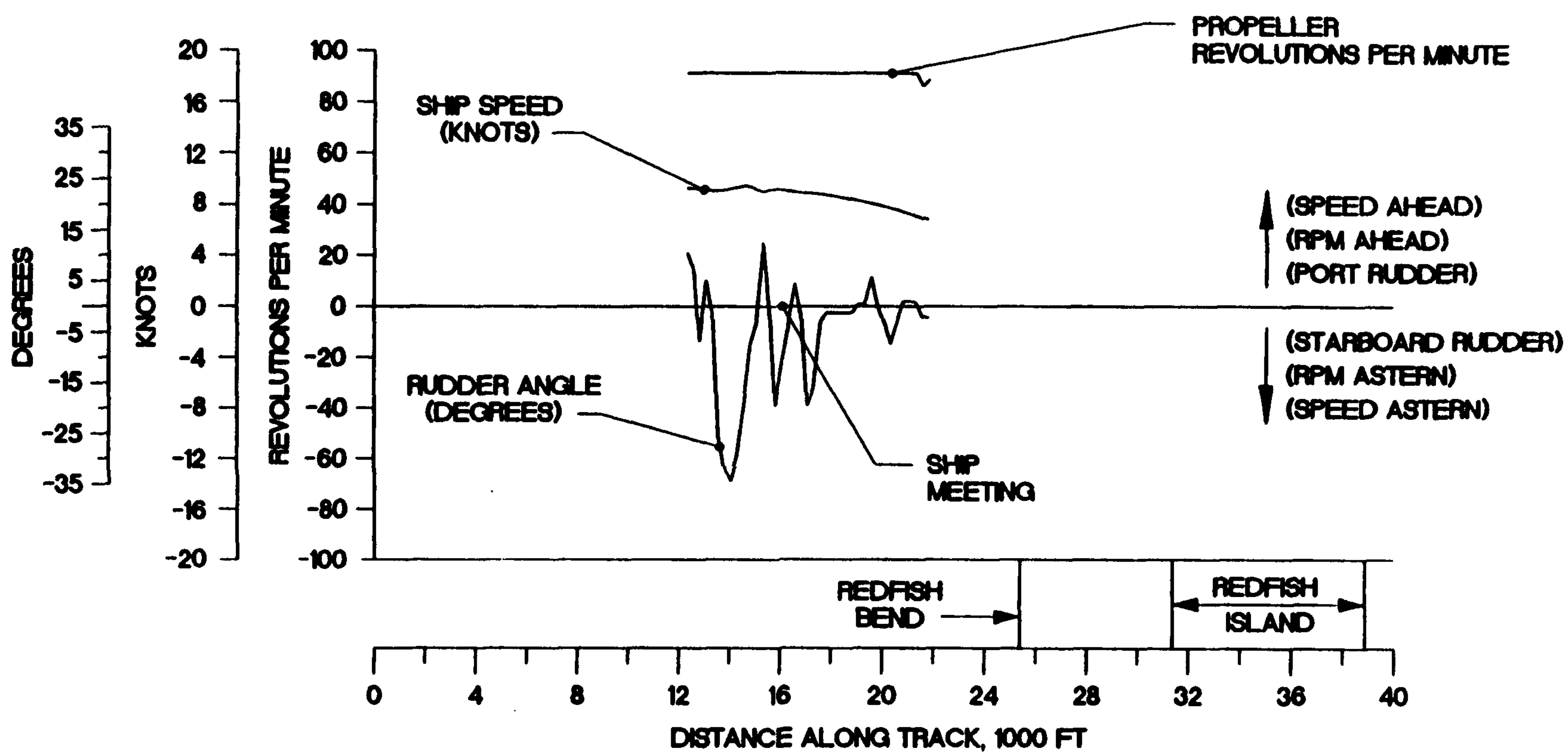
PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT G, RUN 1

PLATE 66

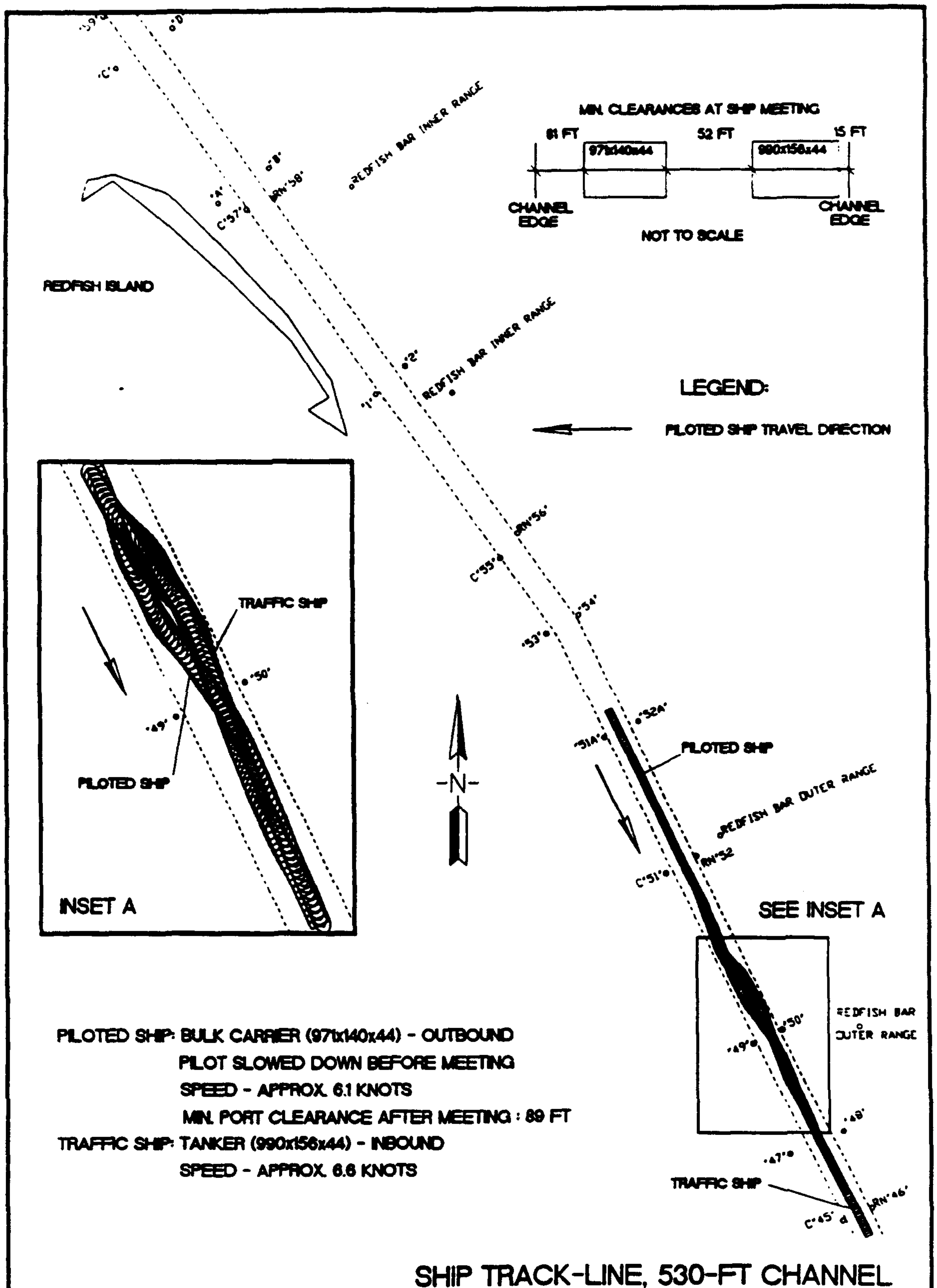


SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT G, RUN 2

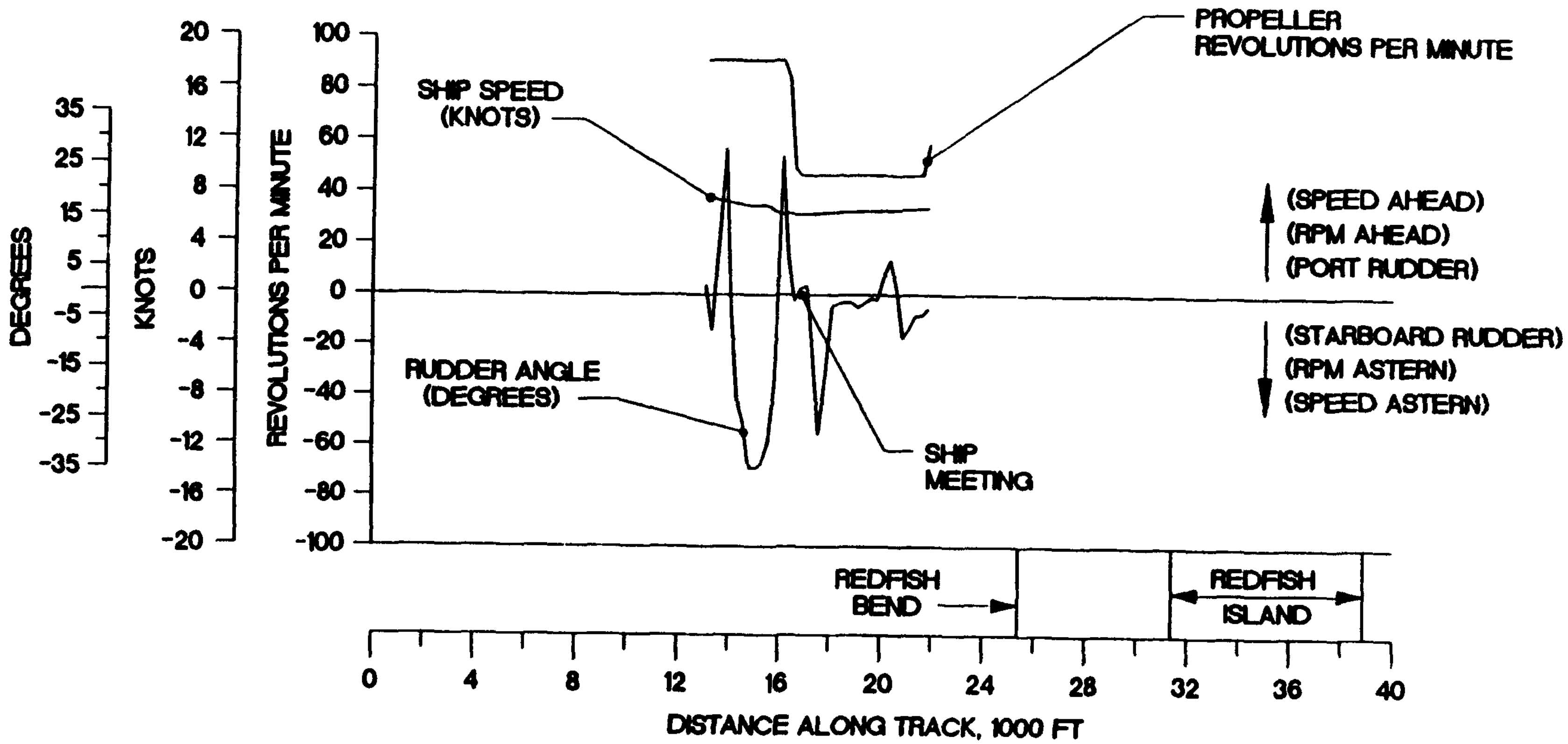


CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT Q, RUN 2

PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND

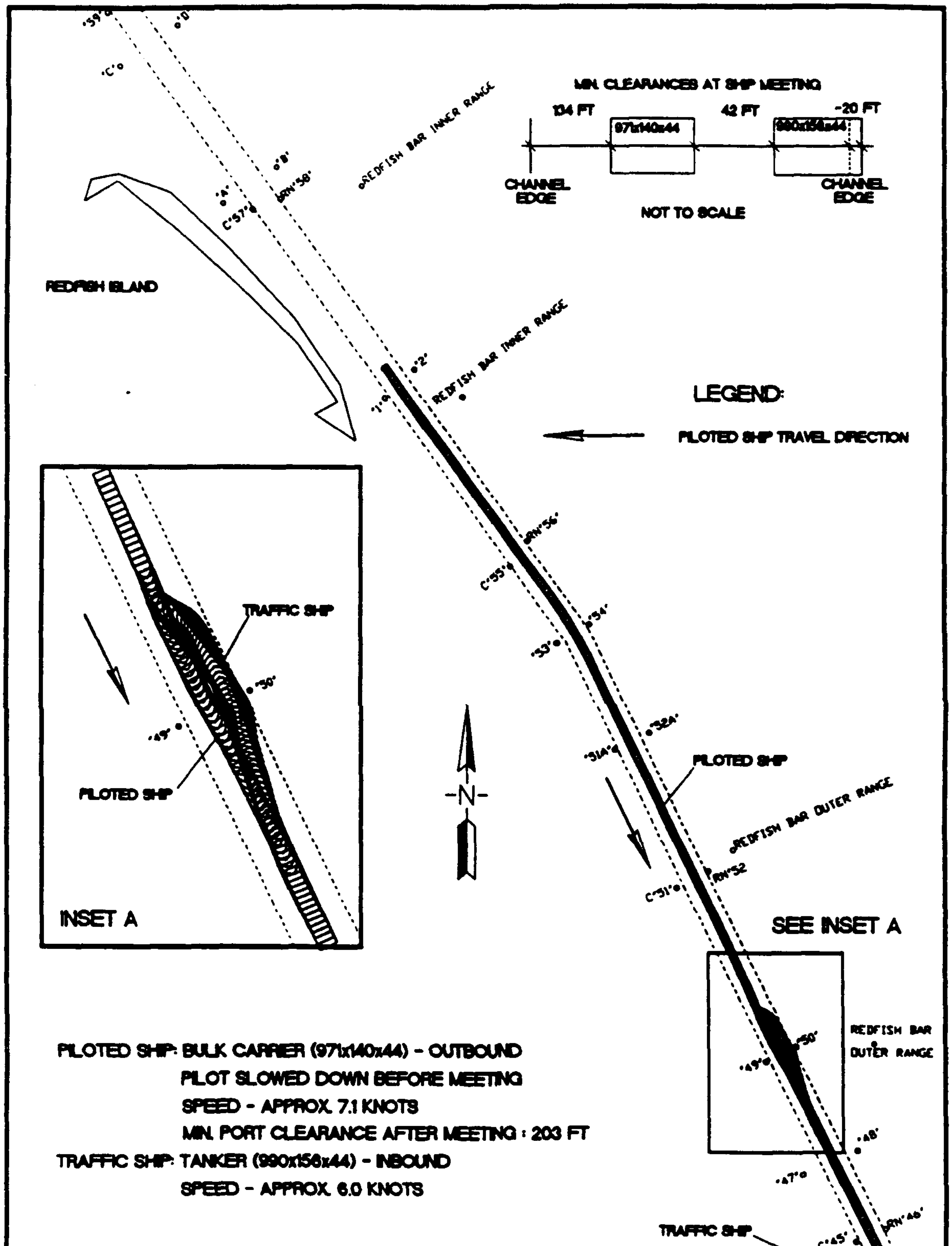


SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT G, RUN 3

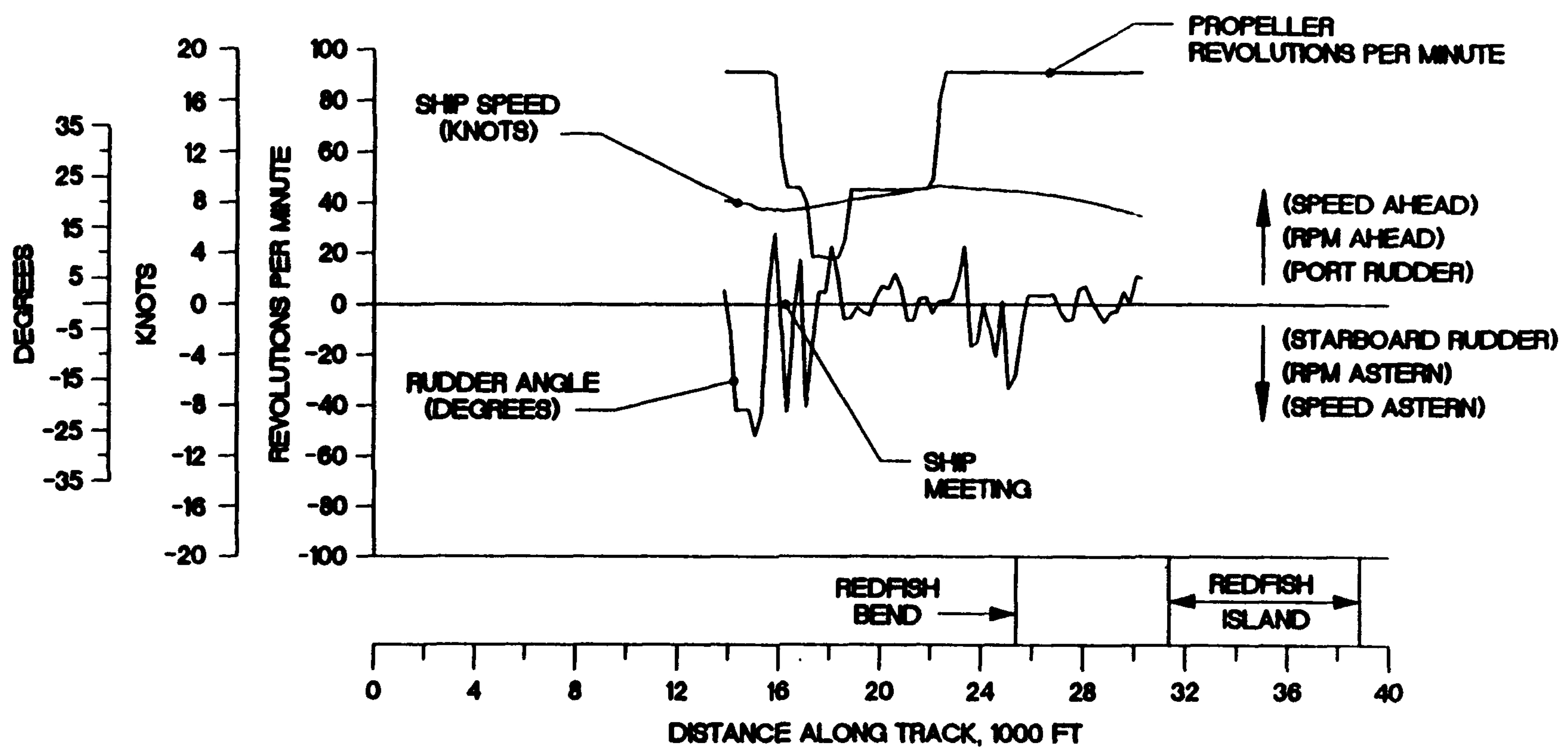


CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT Q, RUN 3

PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND



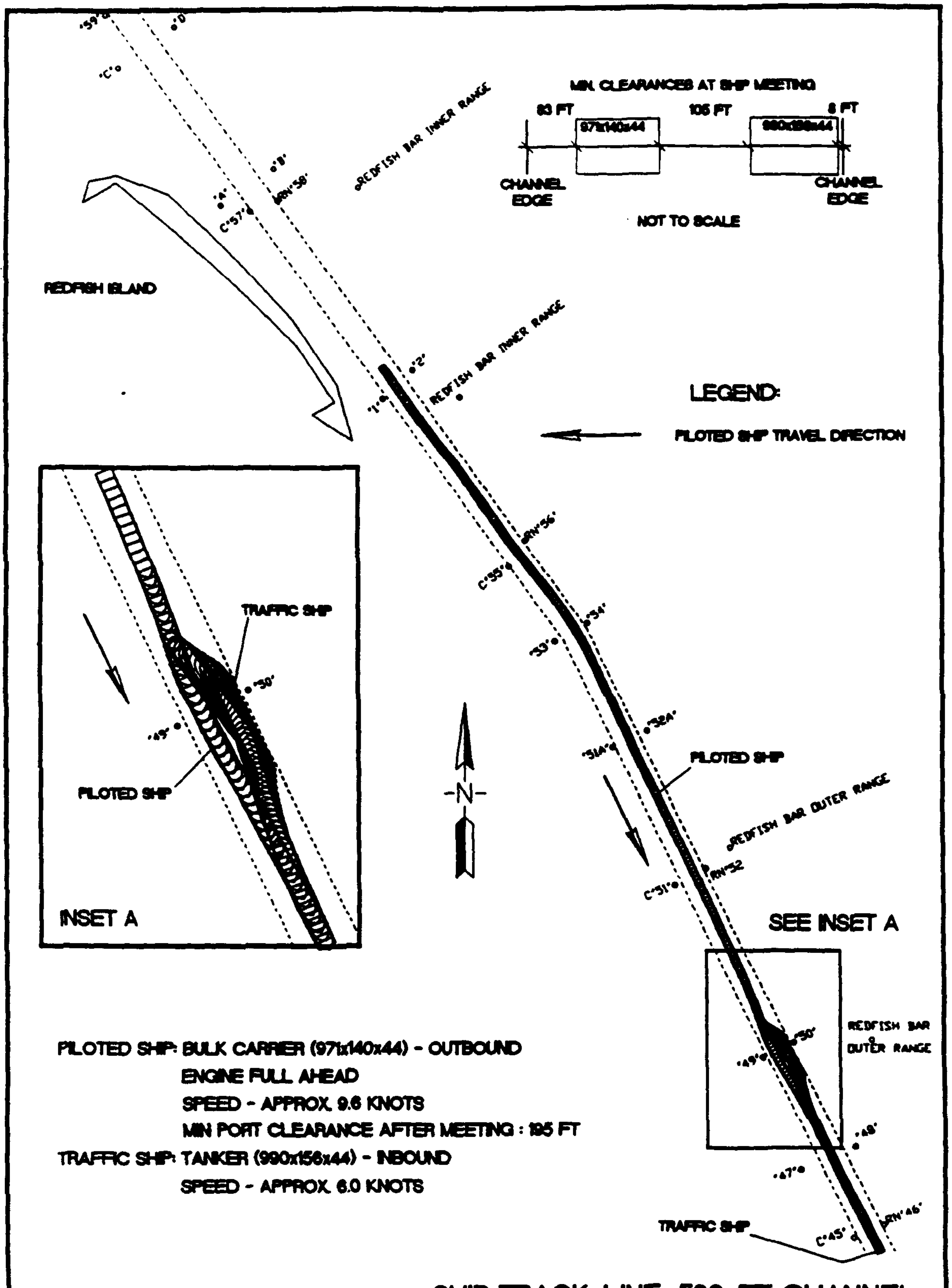
SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H, RUN 1



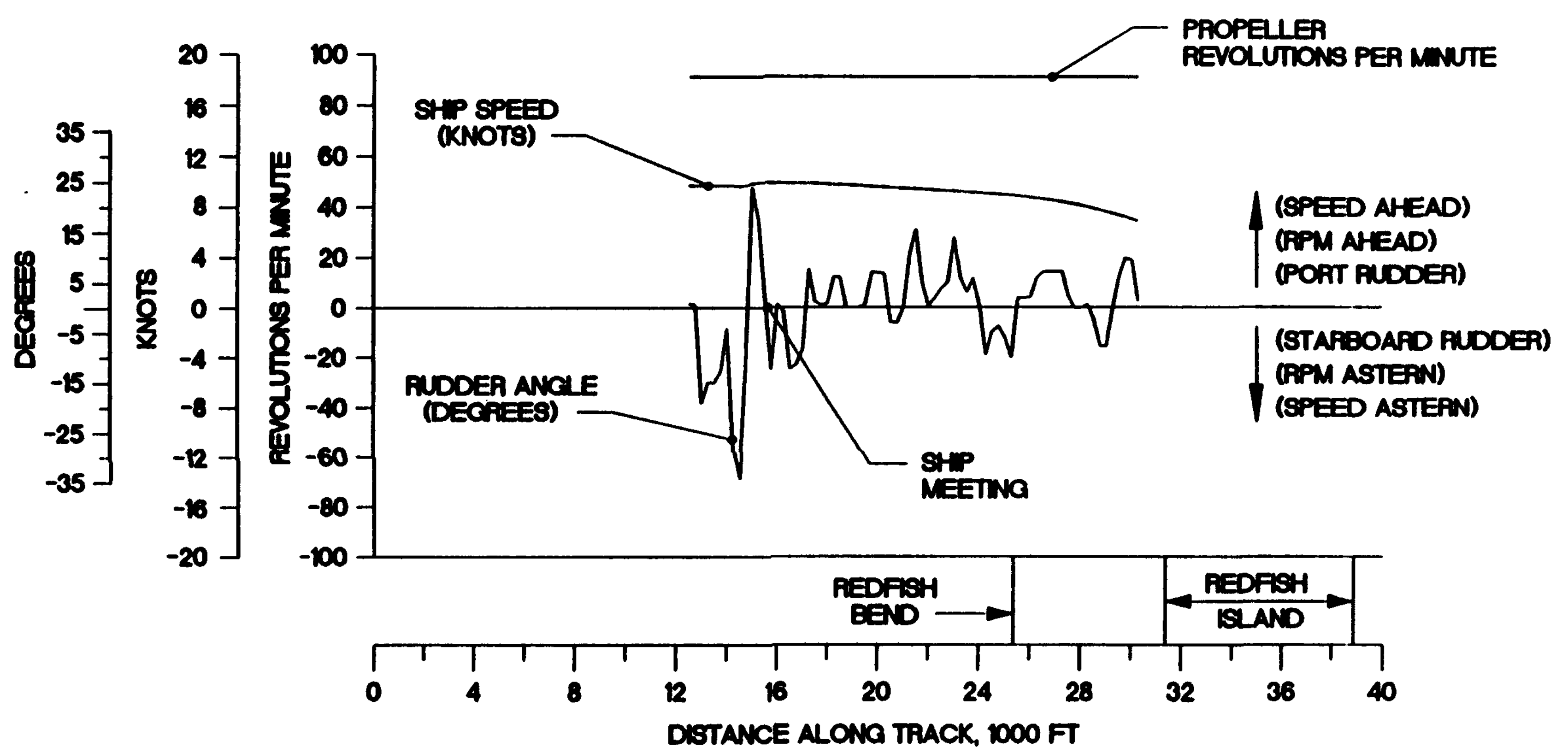
PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H, RUN 1

PLATE 72



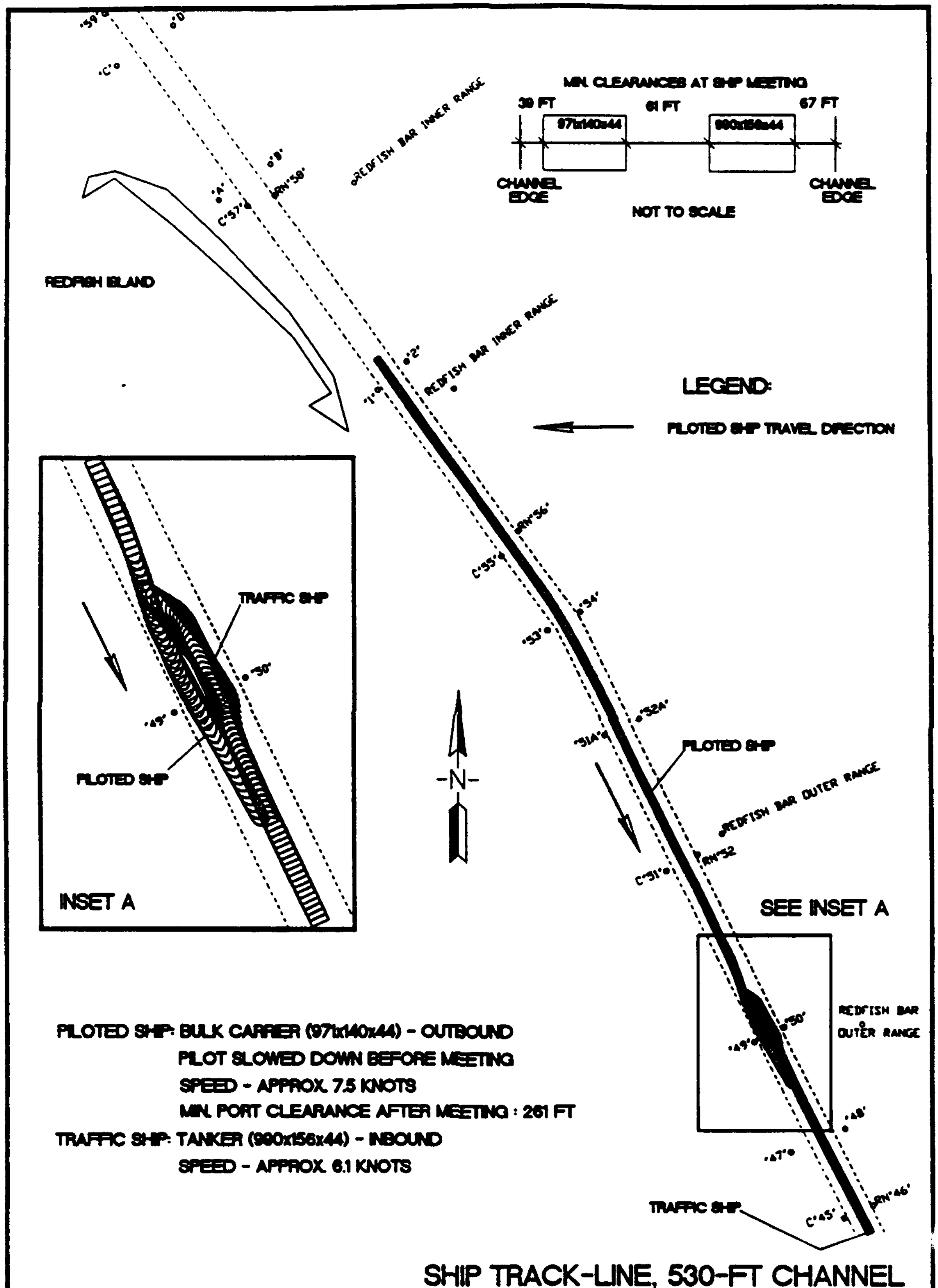
SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT I, RUN 1



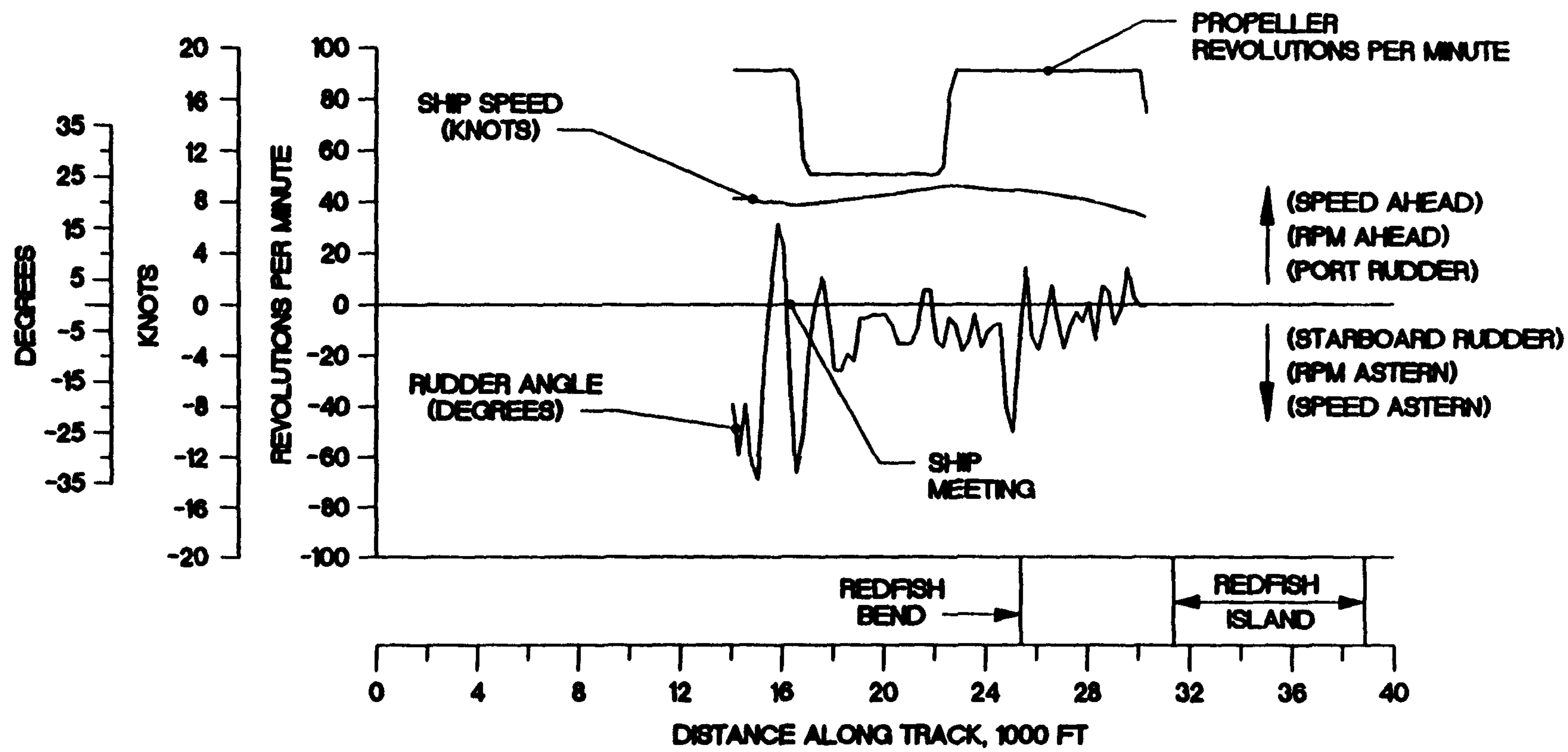
CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT I, RUN 1

PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND

PLATE 74



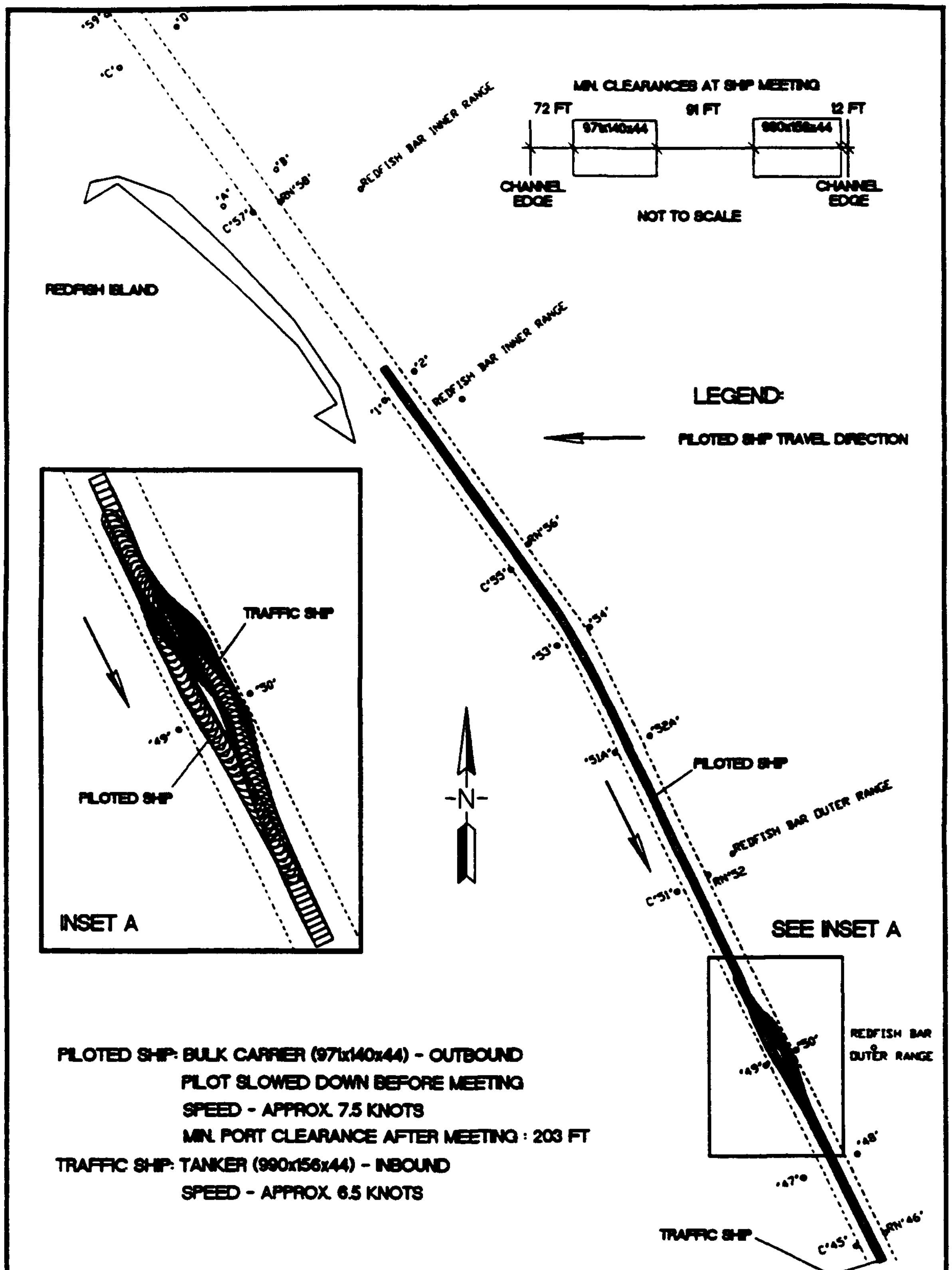
SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT J, RUN 1



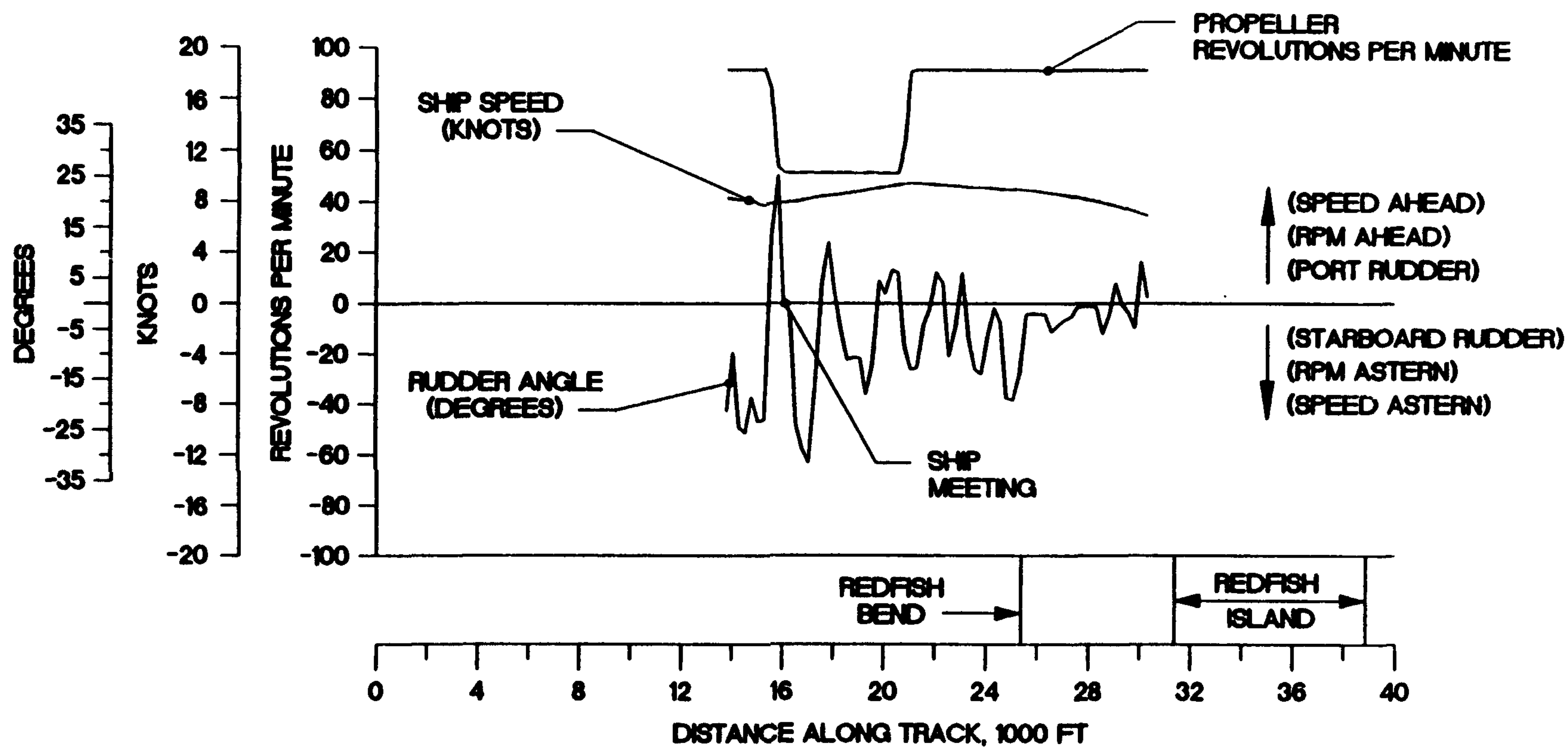
PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT J, RUN 1

PLATE 76



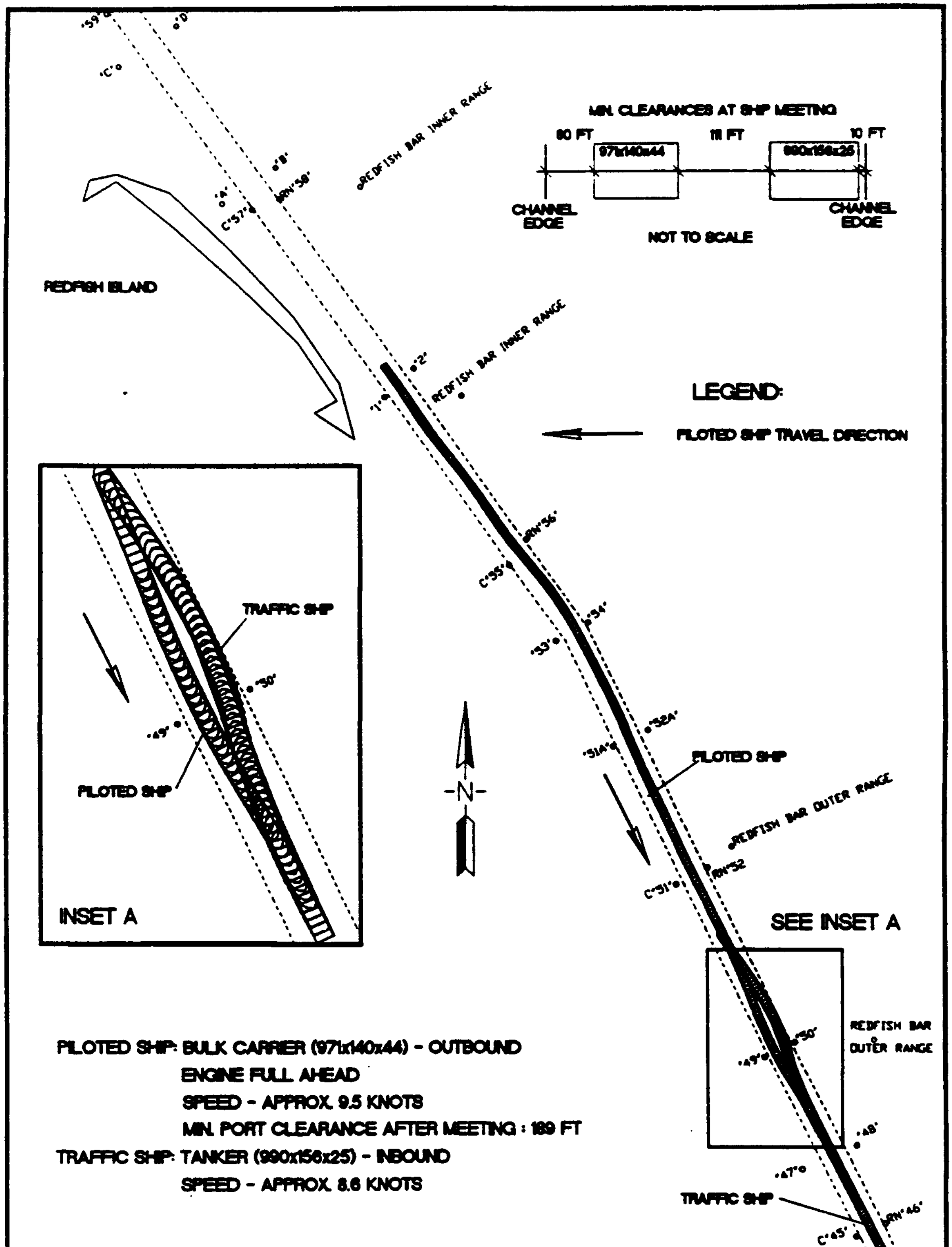
SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT J, RUN 2



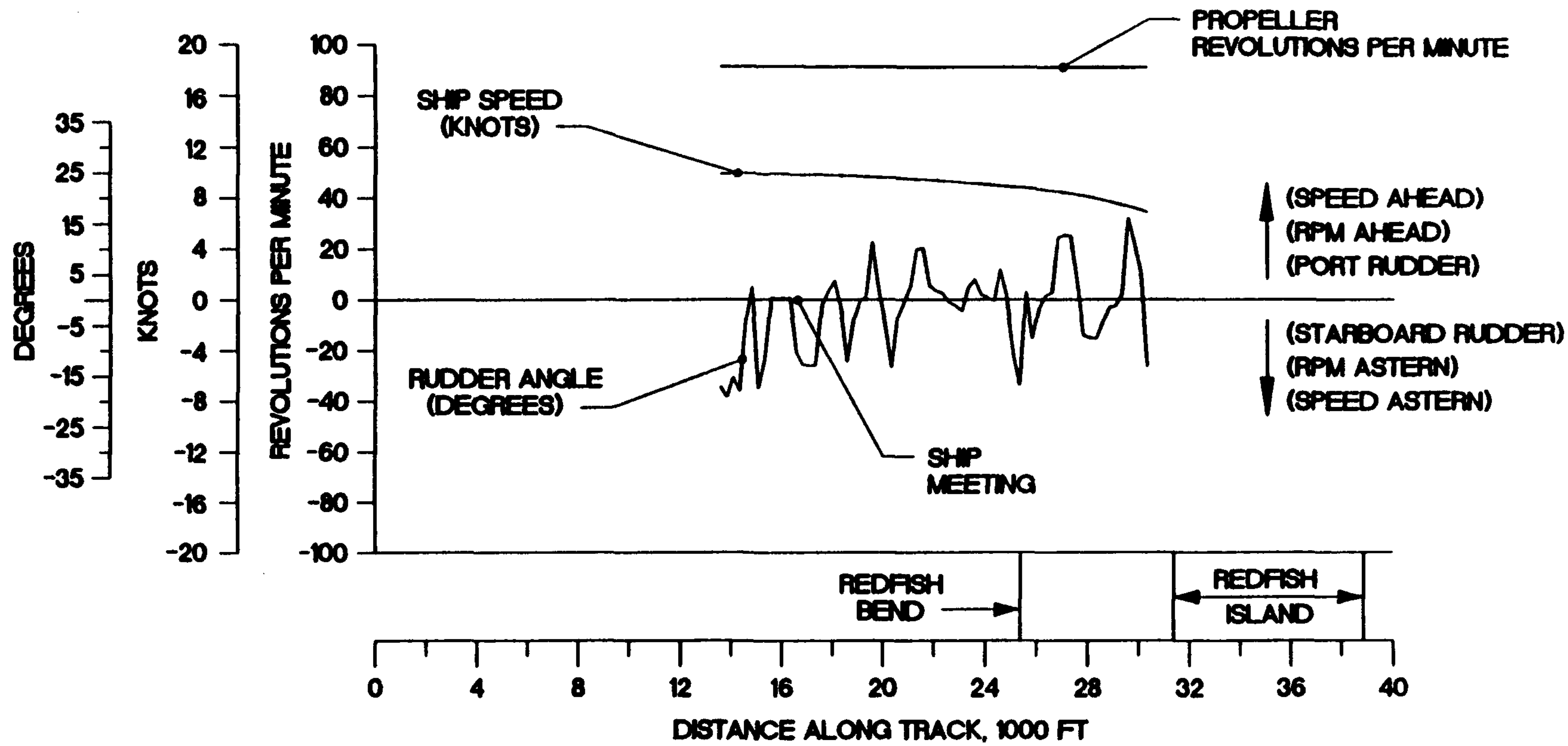
PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x44) - INBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT J, RUN 2

PLATE 78

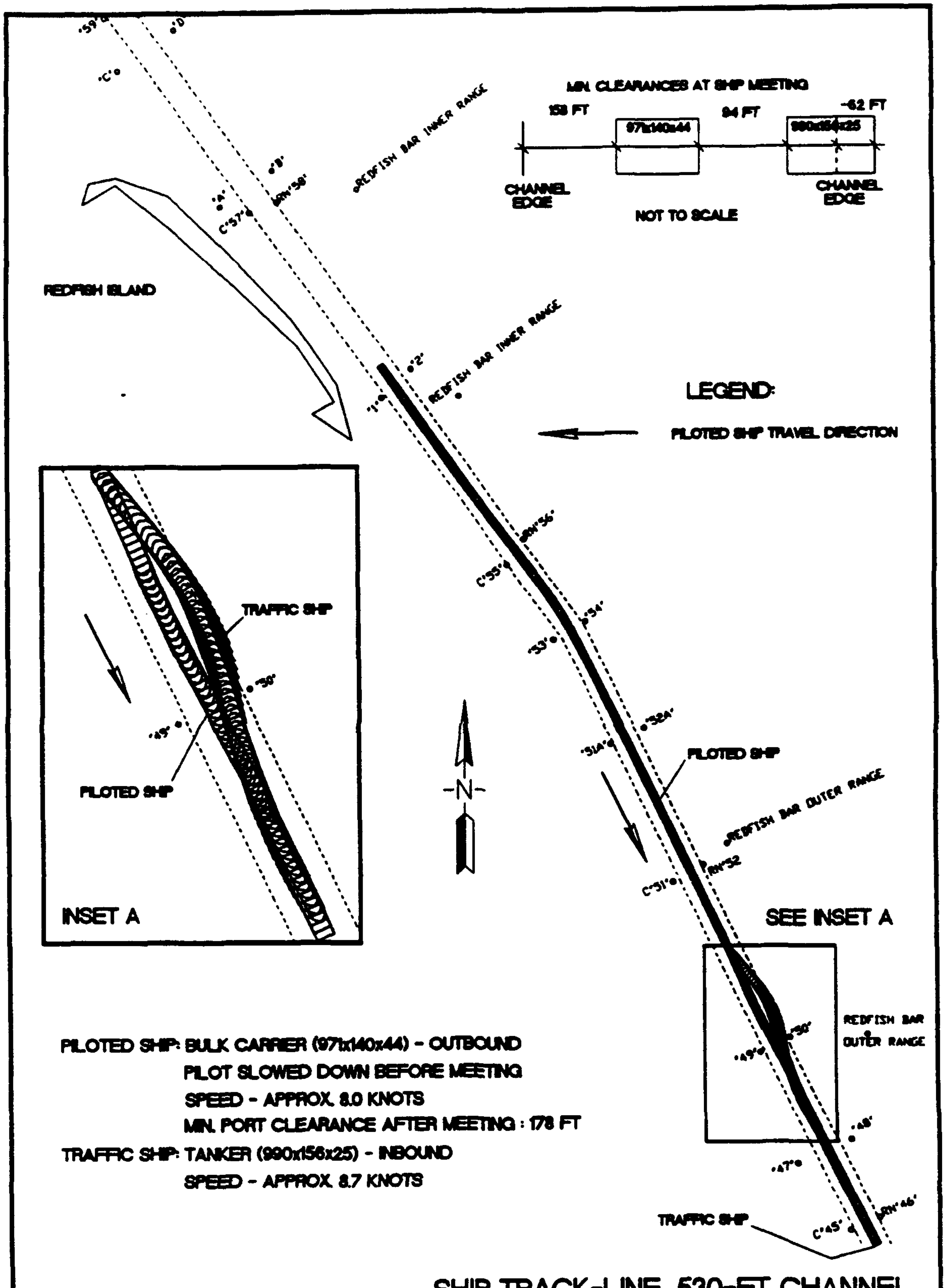


SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 3

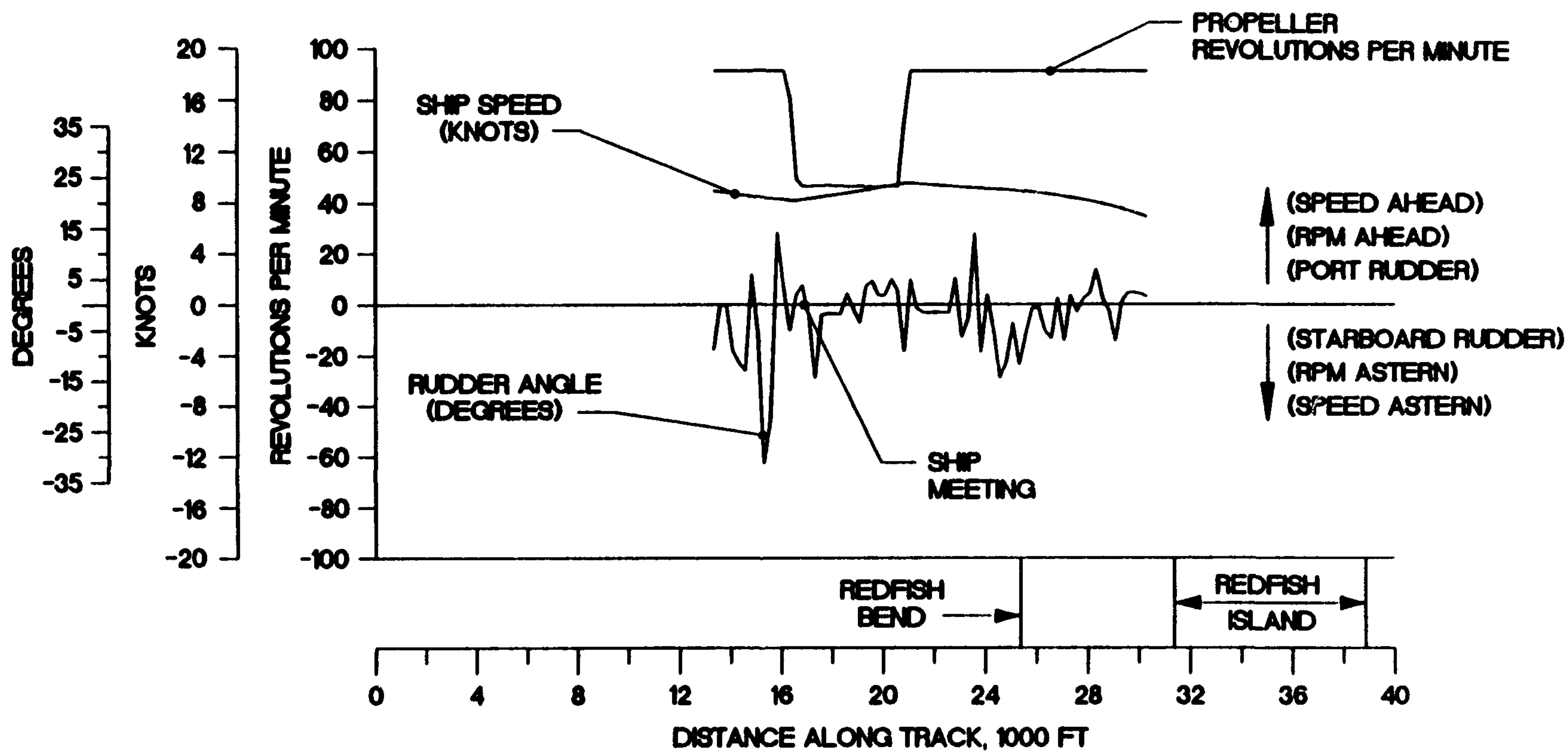


PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x25) - INBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 3



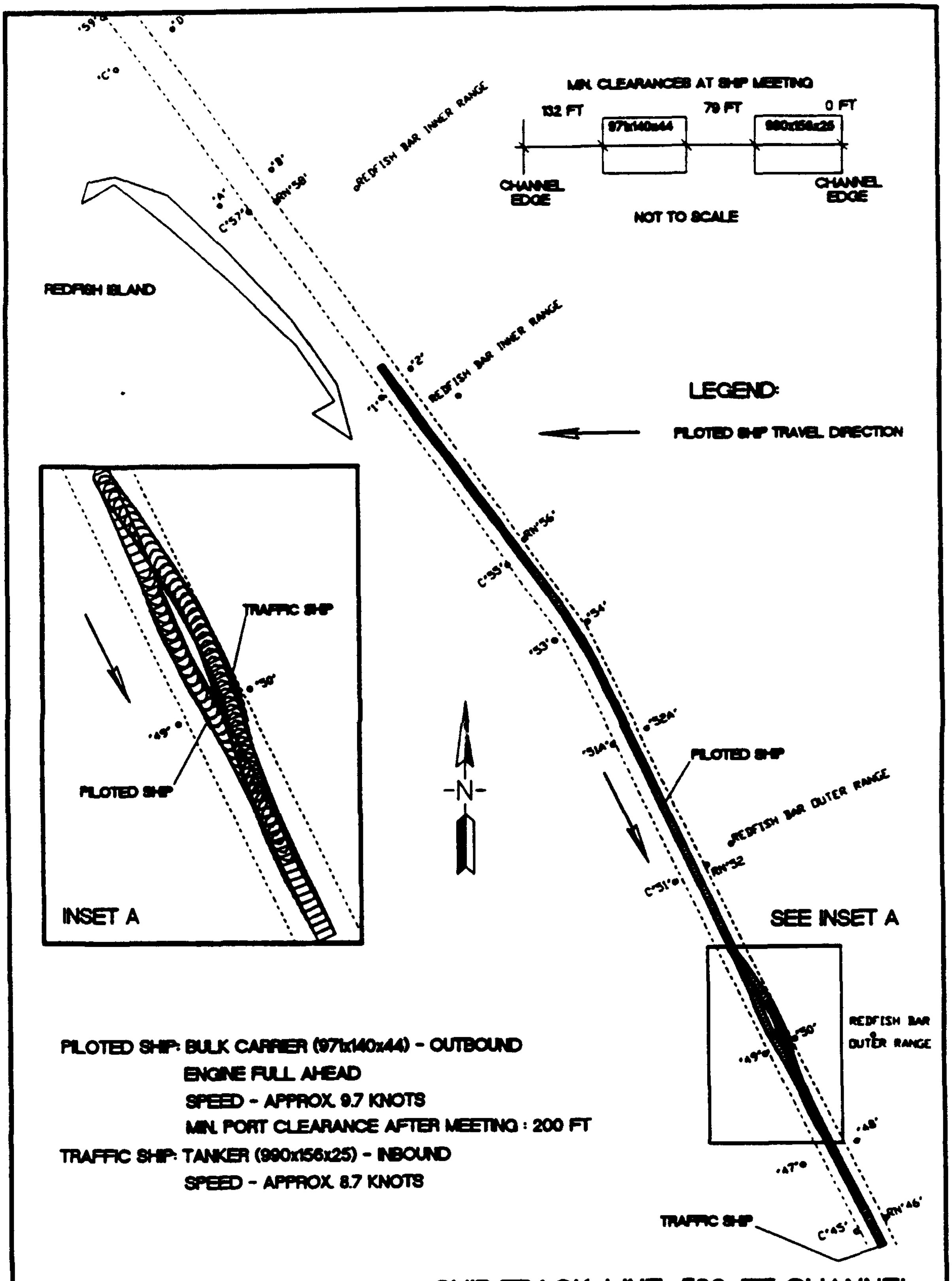
SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H, RUN 2



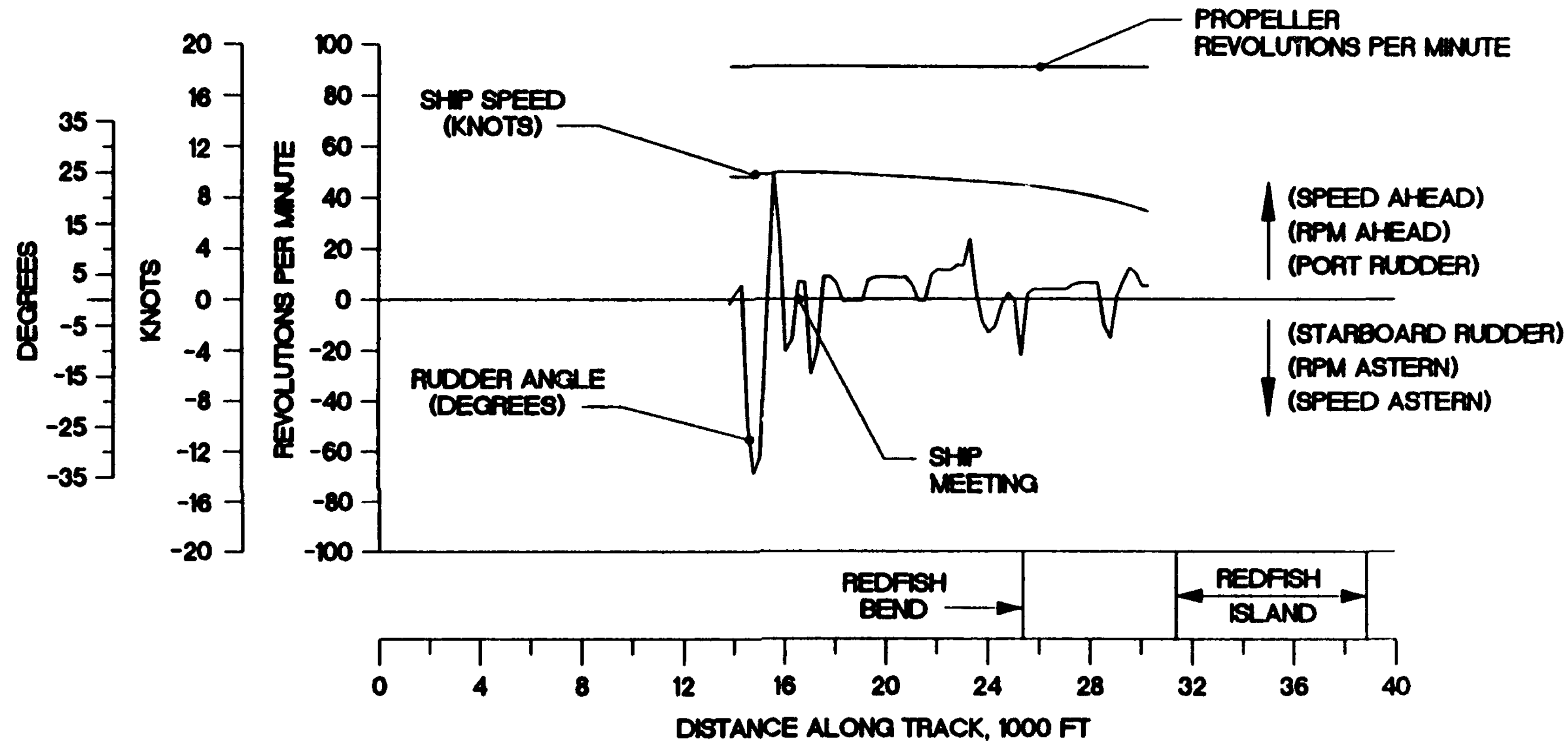
PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x25) - INBOUND

CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H, RUN 2

PLATE 82



SHIP TRACK-LINE, 530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT I, RUN 2

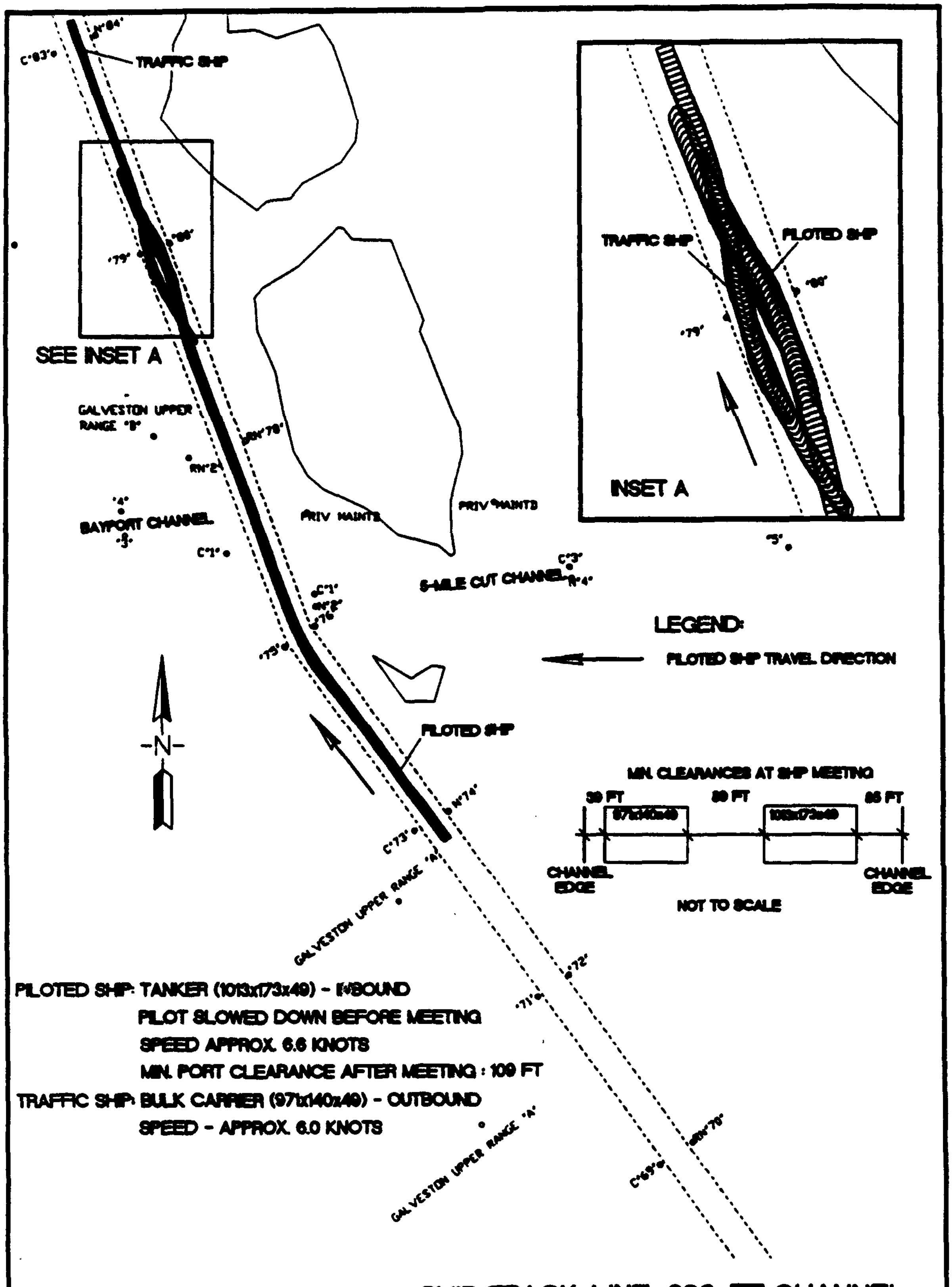


PILOTED SHIP: BULK CARRIER (971x140x44) - OUTBOUND
TRAFFIC SHIP: TANKER (990x156x25) - INBOUND

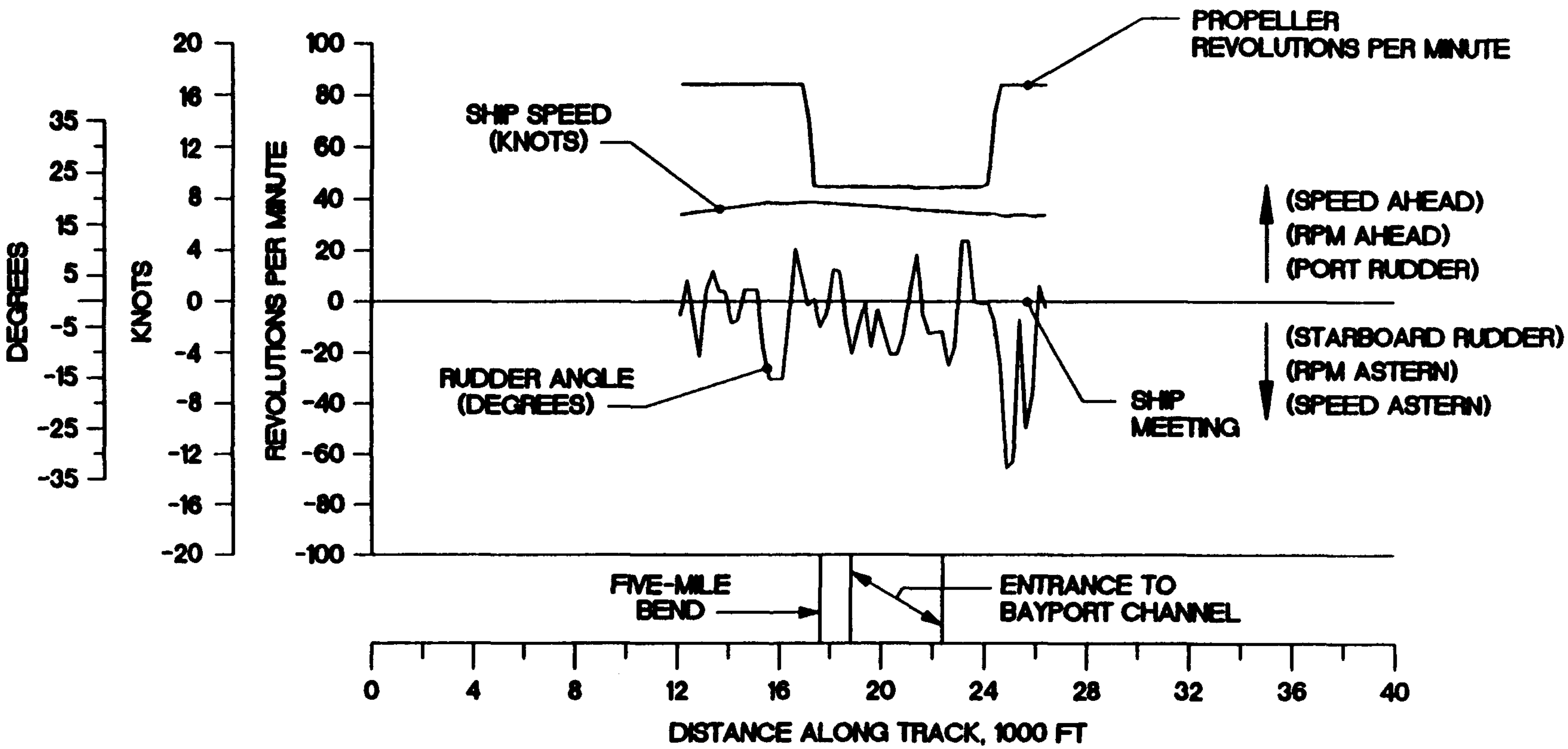
CONTROL MEASURES
PILOTED SHIP
530-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT I, RUN 2

PLATE 84

600-ft Channel Simulator Tests

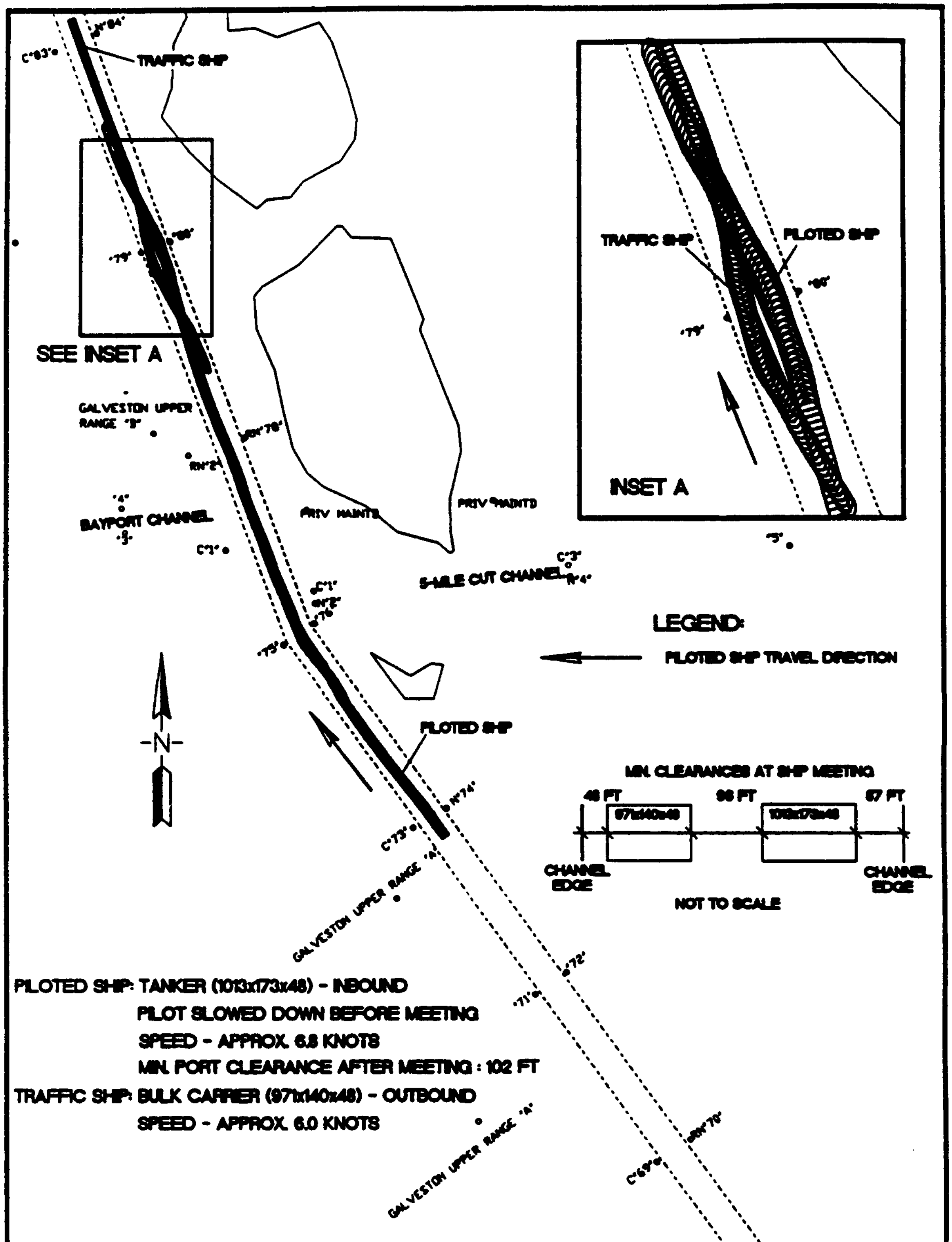


SHIP TRACK-LINE, 600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 1

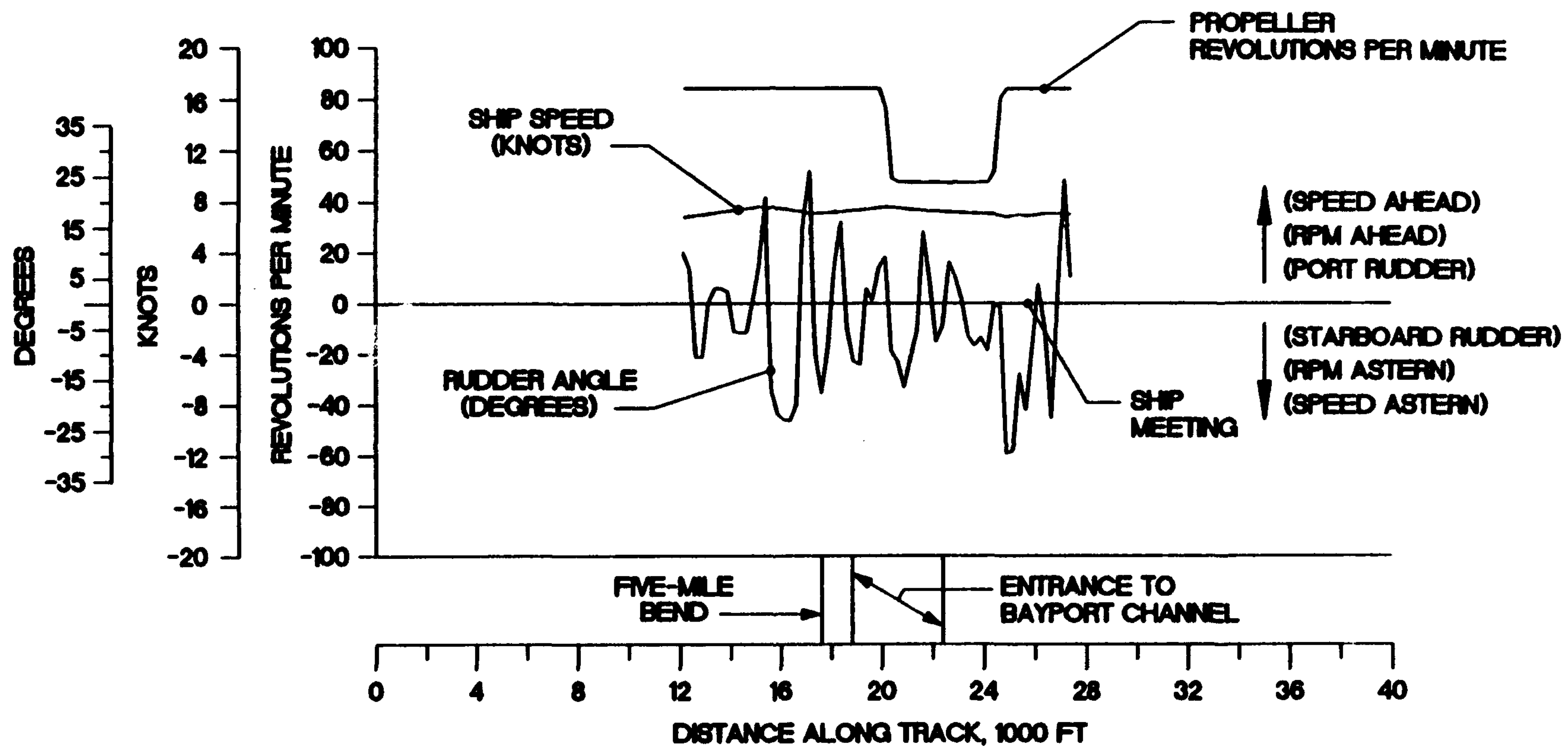


PILOTED SHIP: TANKER (1013x173x49) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x49) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 1



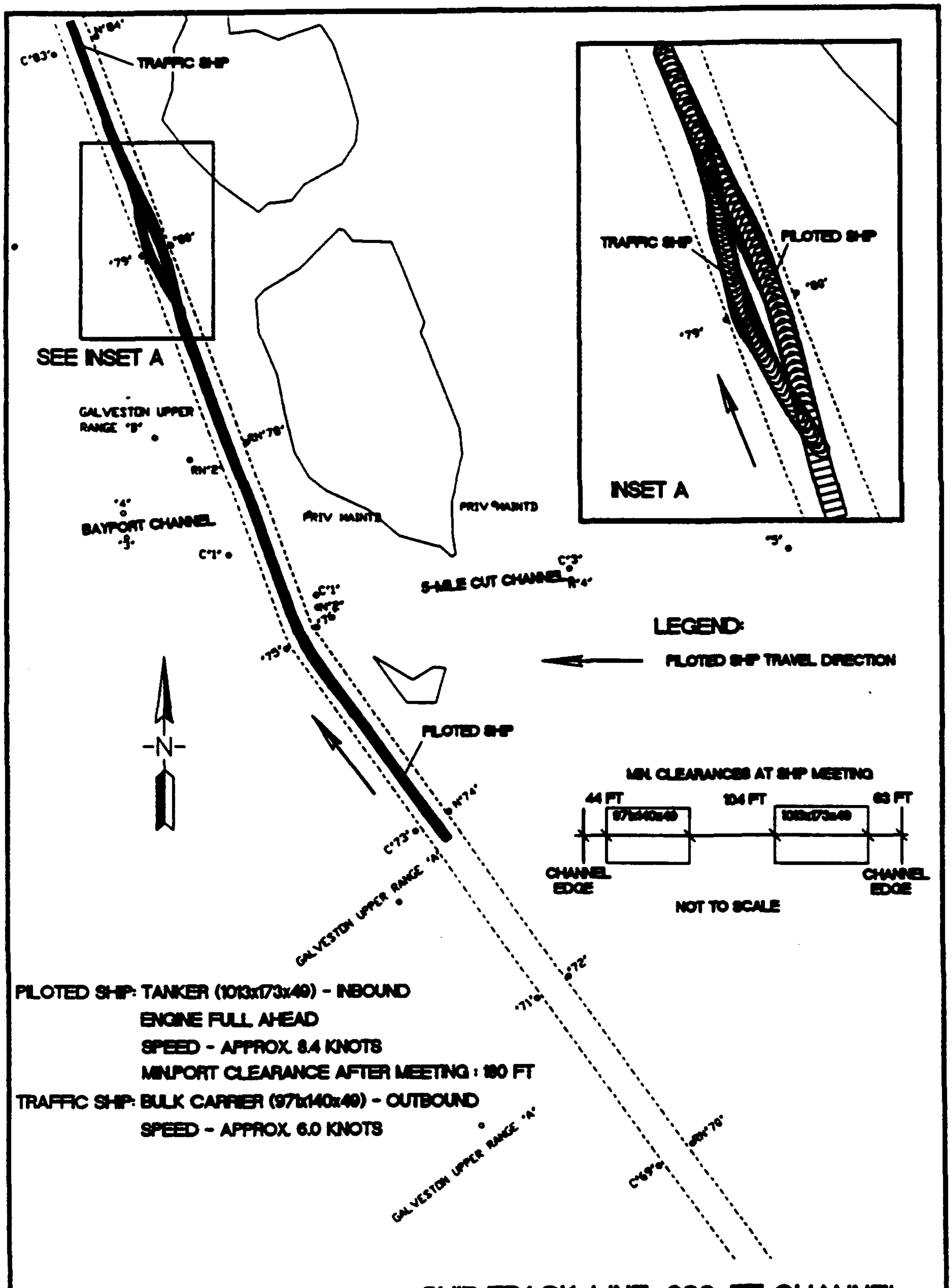
SHIP TRACK-LINE, 600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 2



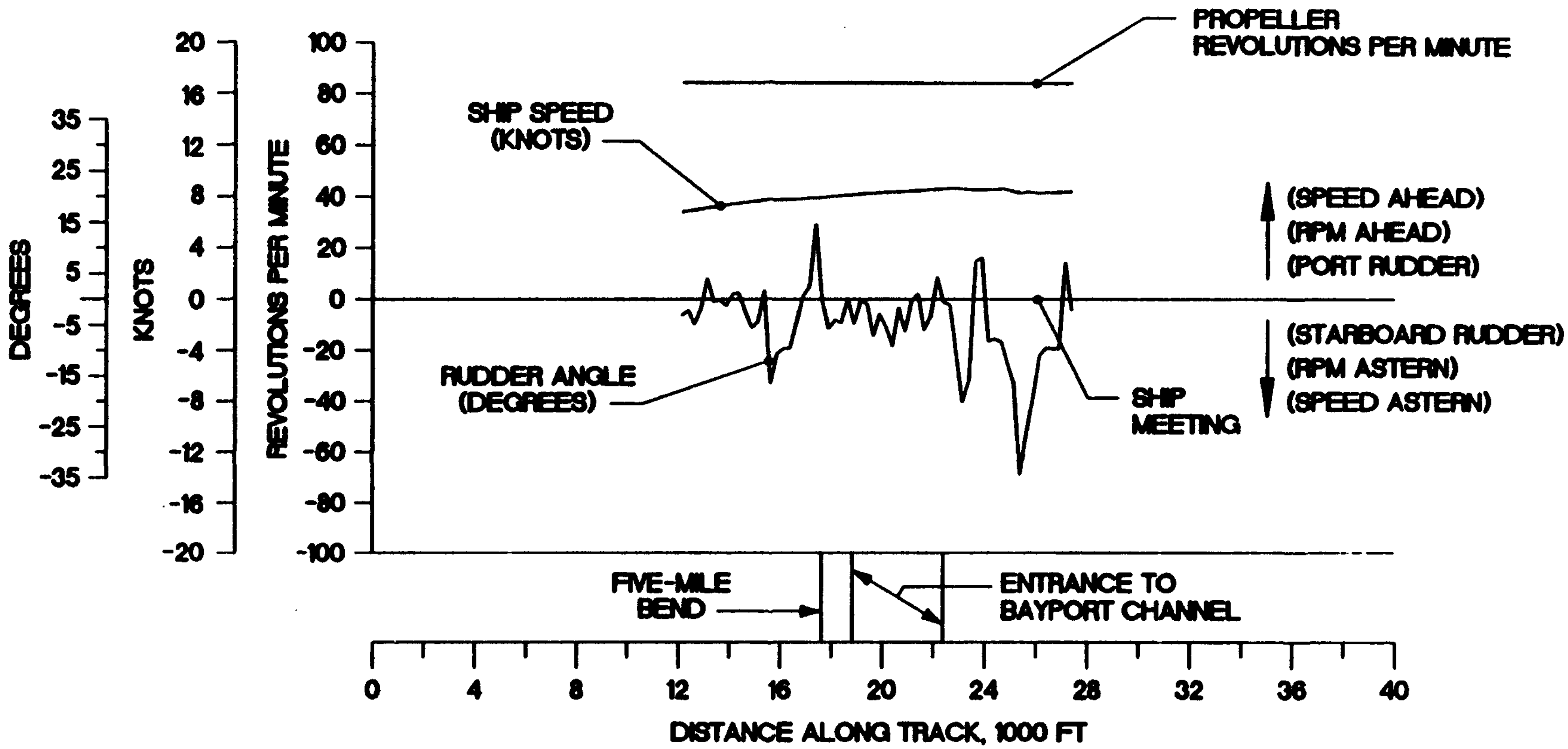
CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL

BAYPORT VICINITY
FLOOD TIDE, PILOT F, RUN 2

PILOTED SHIP: TANKER (1013x173x48) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x48) - OUTBOUND



SHIP TRACK-LINE, 600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 1

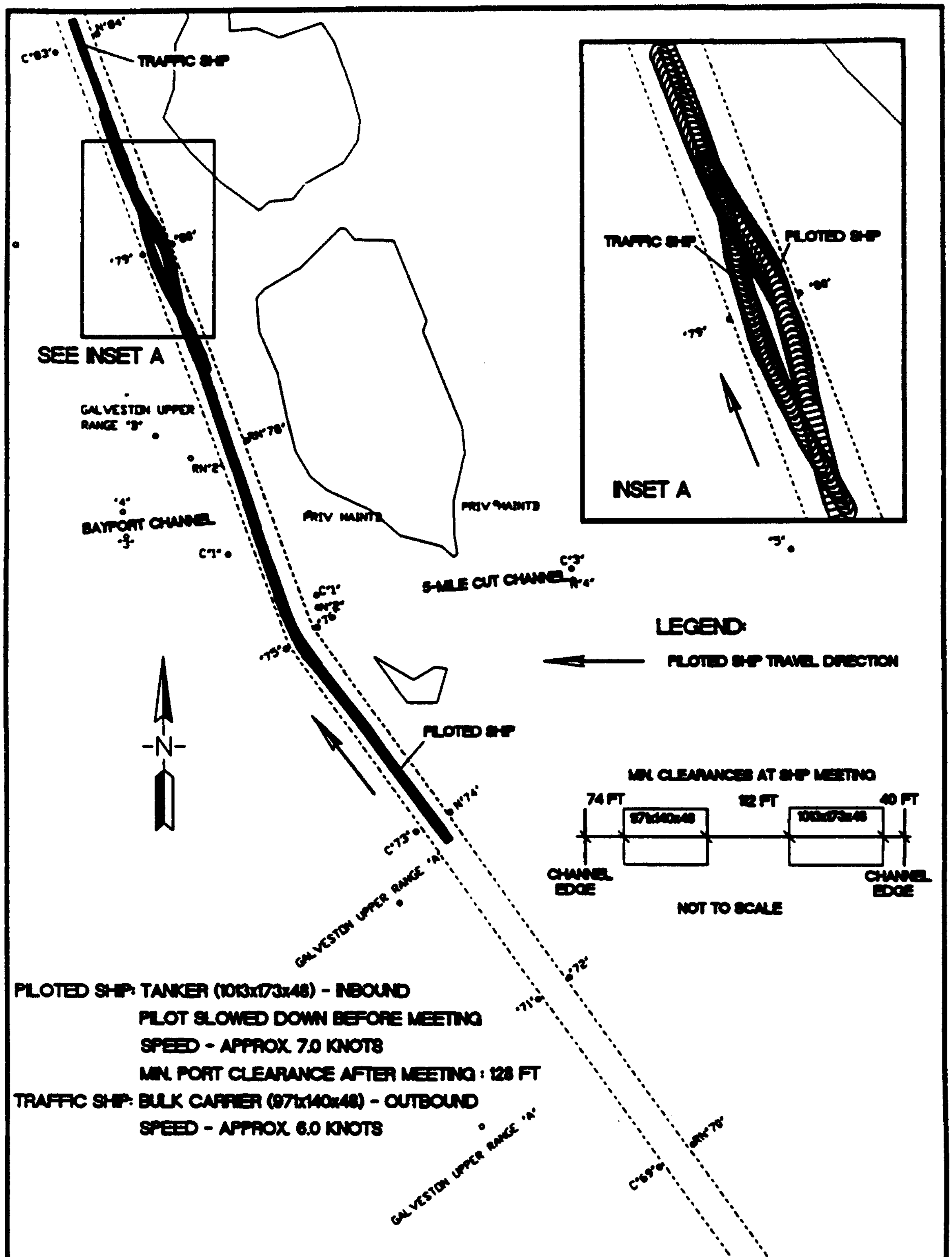


PILOTED SHIP: TANKER (1013x173x49) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x49) - OUTBOUND

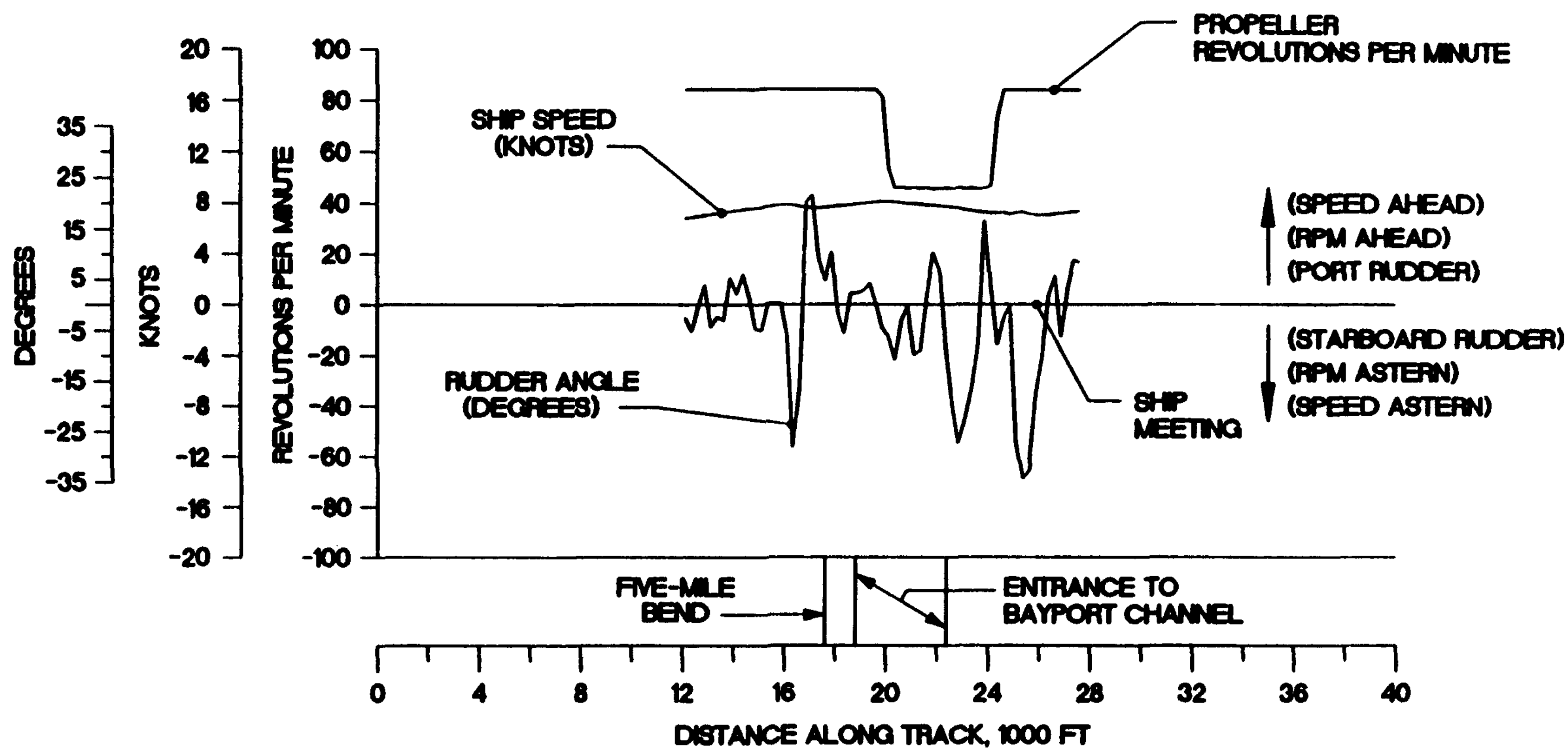
CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL

BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 1

PLATE 90



SHIP TRACK-LINE, 600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT G, RUN 2

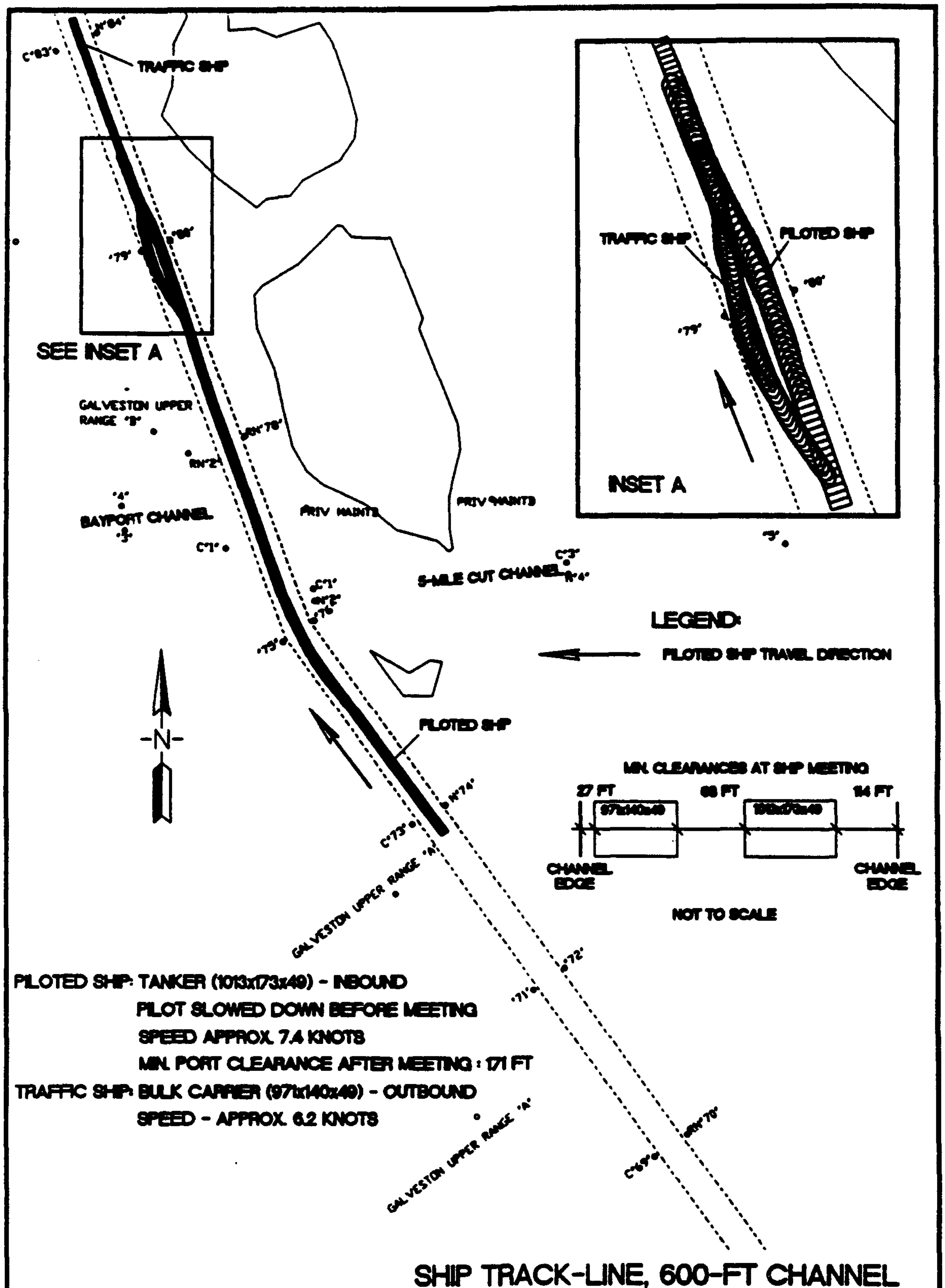


PILOTED SHIP: TANKER (1013x173x48) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x48) - OUTBOUND

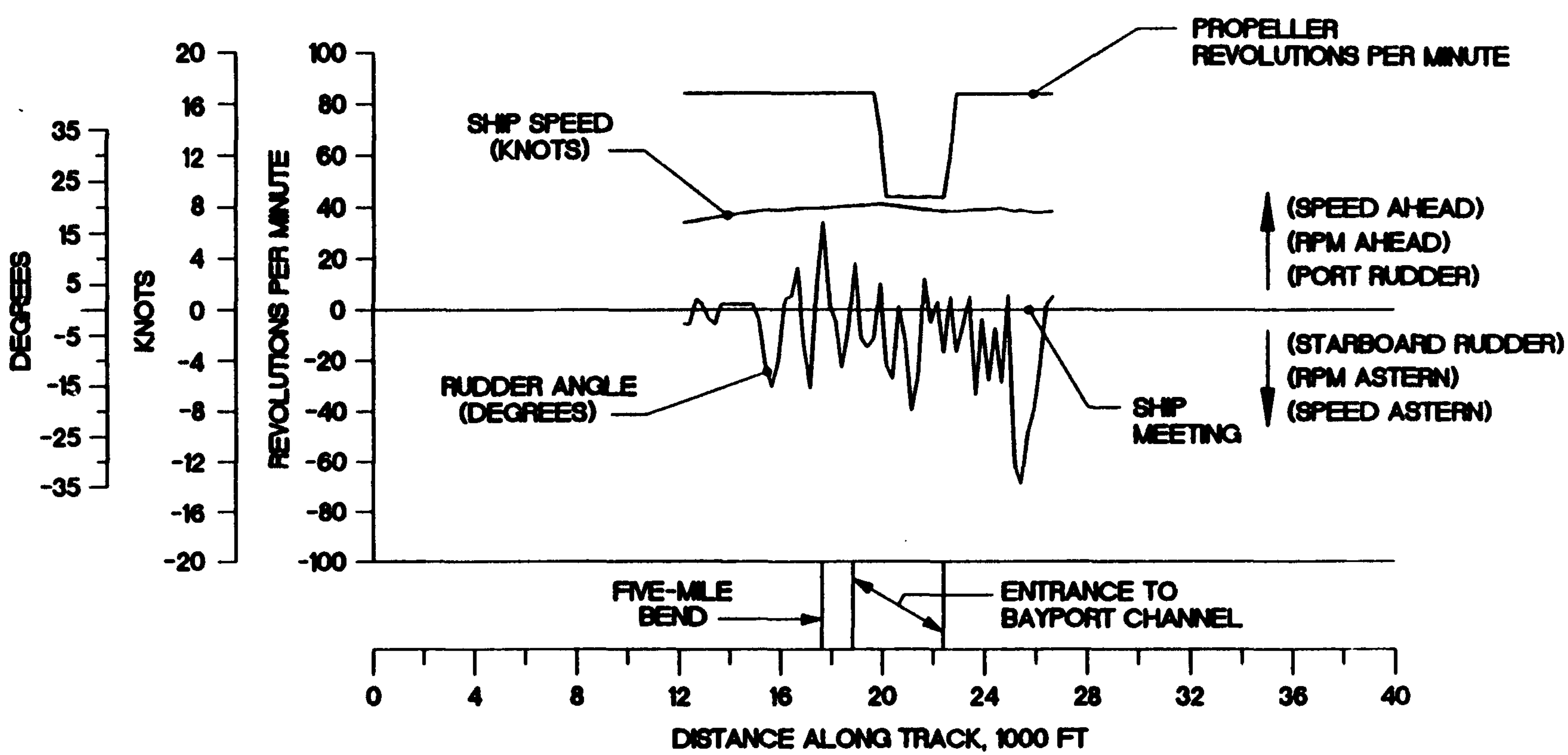
CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL

BAYPORT VICINITY
FLOOD TIDE, PILOT Q, RUN 2

PLATE 92



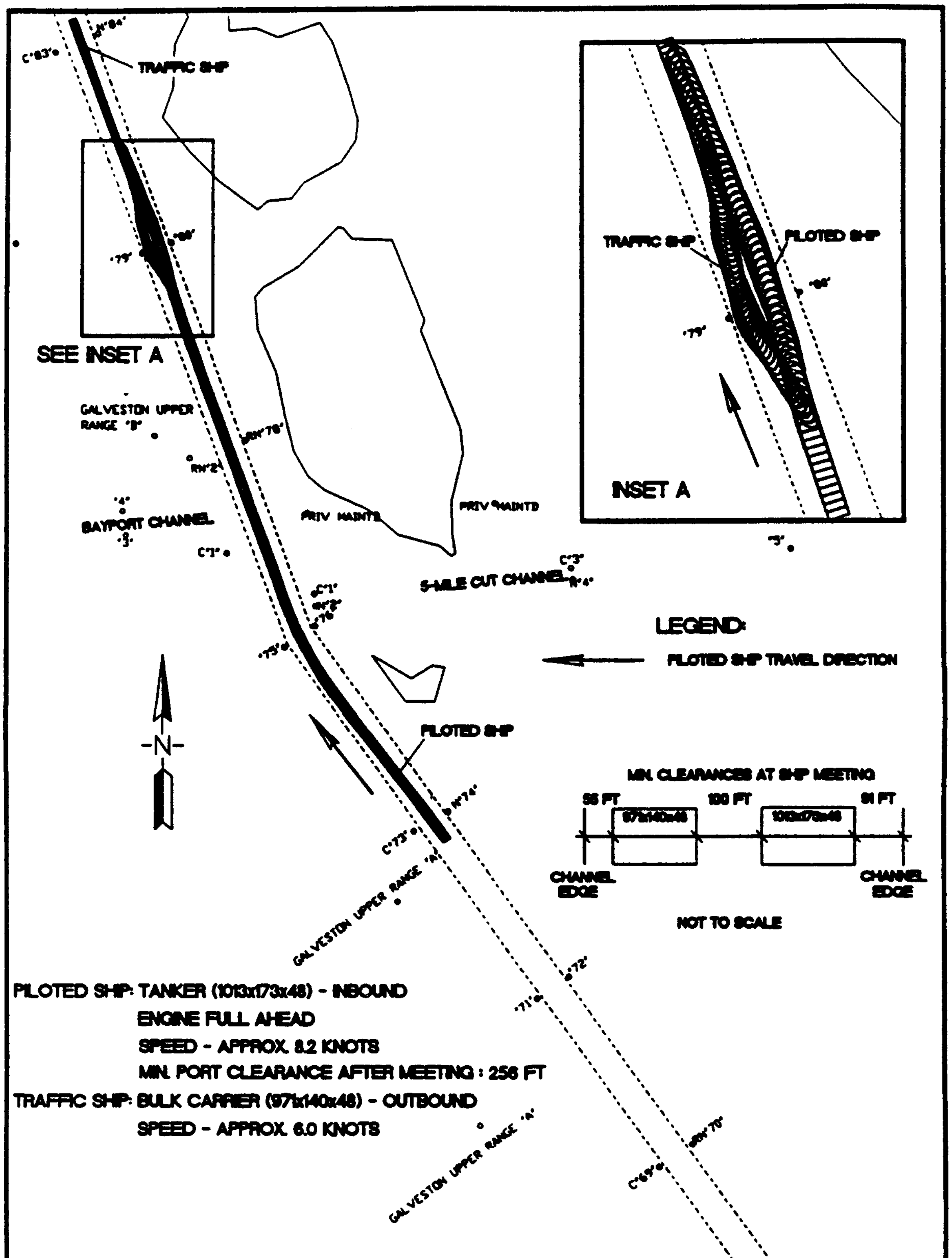
SHIP TRACK-LINE, 600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 1



PILOTED SHIP: TANKER (1013x173x49) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x49) - OUTBOUND

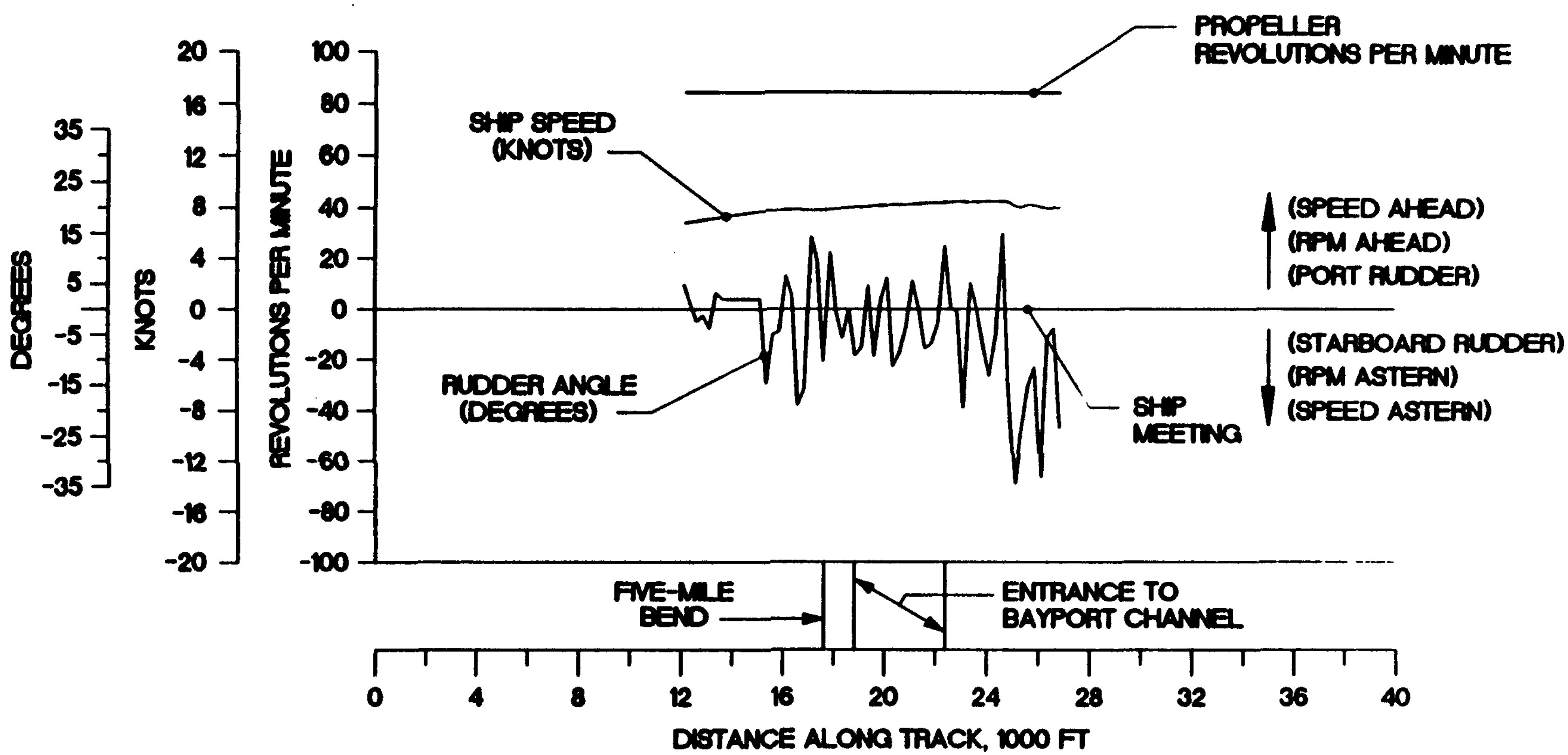
CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 1

PLATE 94



SHIP TRACK-LINE, 600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 2

PLATE 95

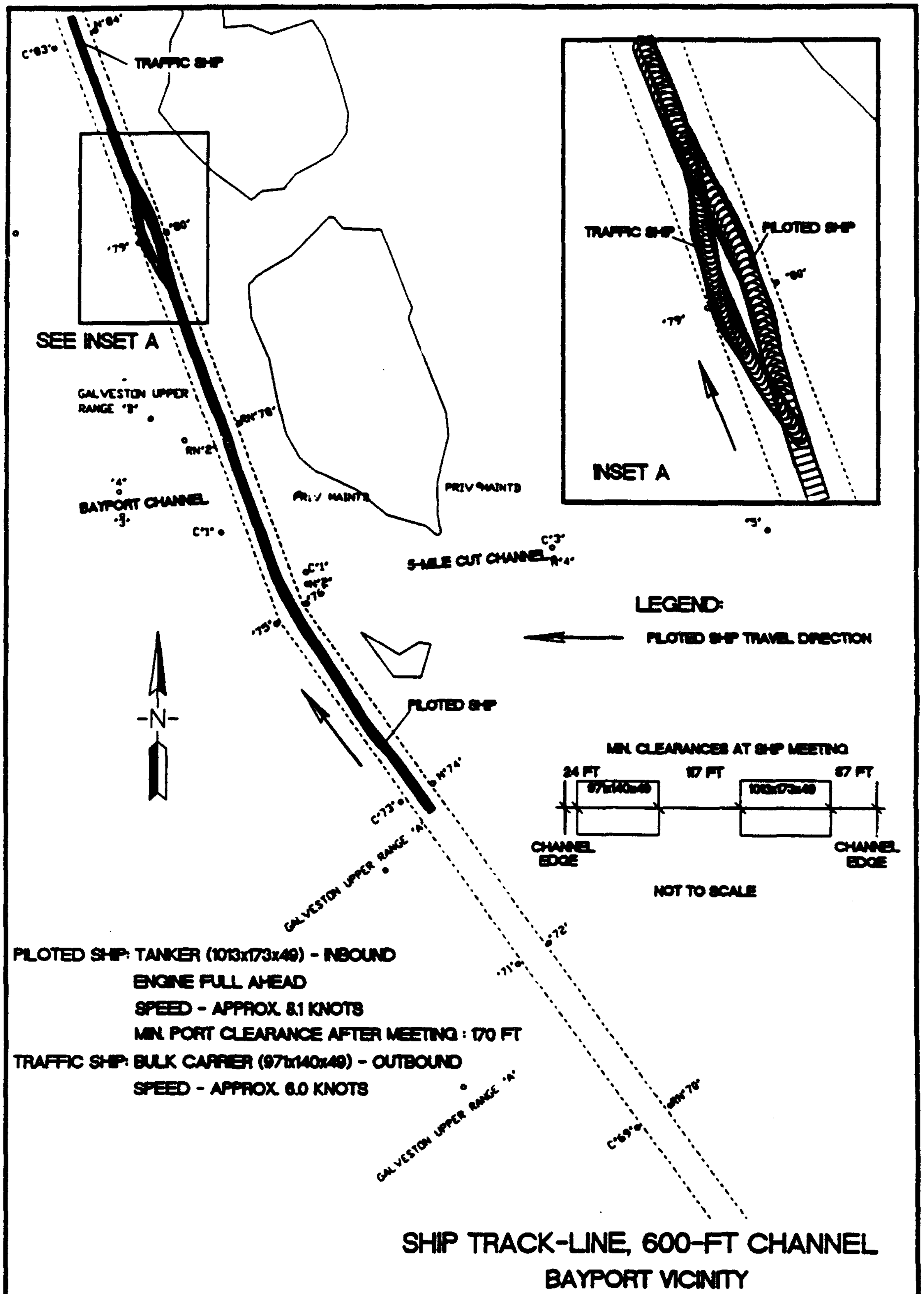


CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL

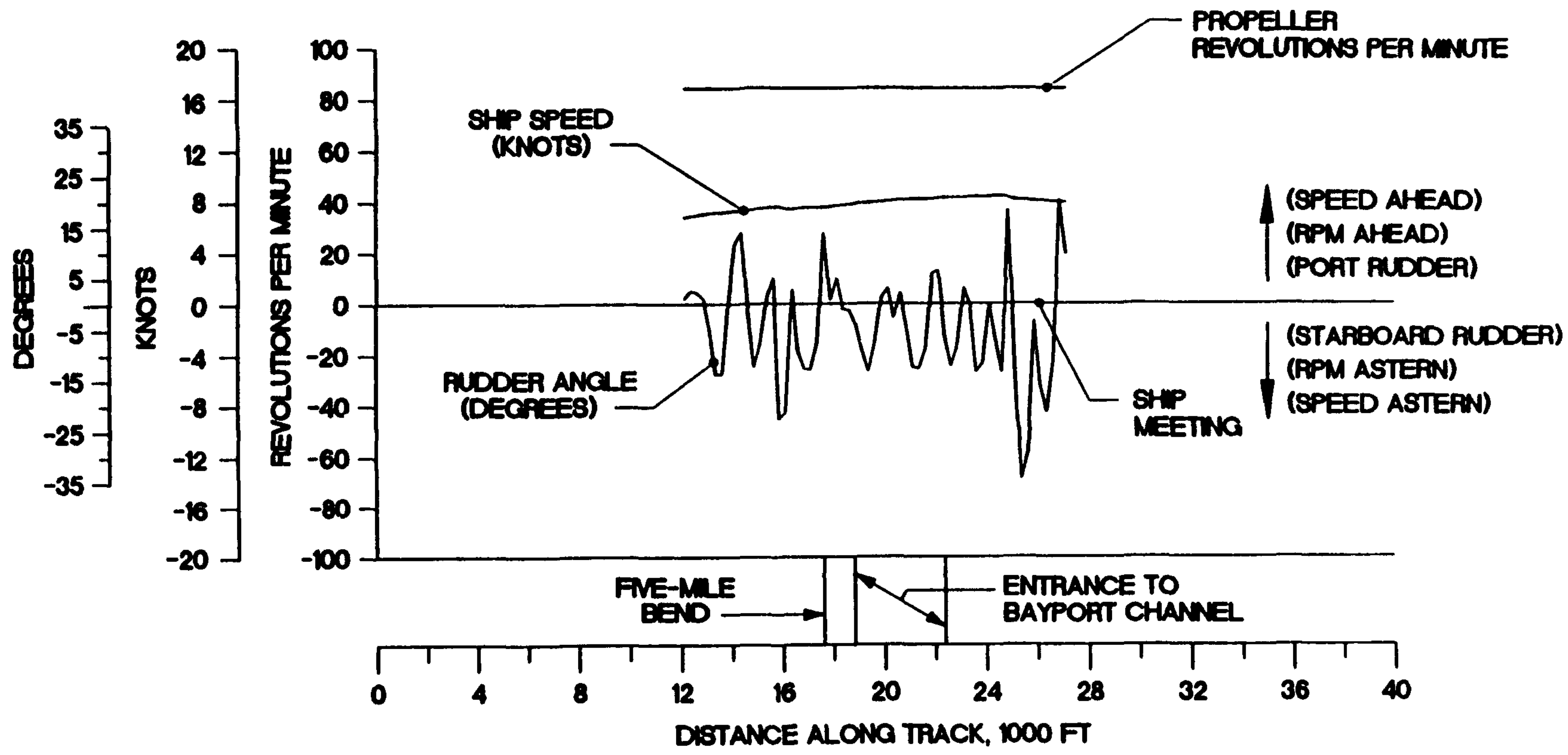
BAYPORT VICINITY
FLOOD TIDE, PILOT H, RUN 2

PILOTED SHIP: TANKER (1013x173x48) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x48) - OUTBOUND

PLATE 96



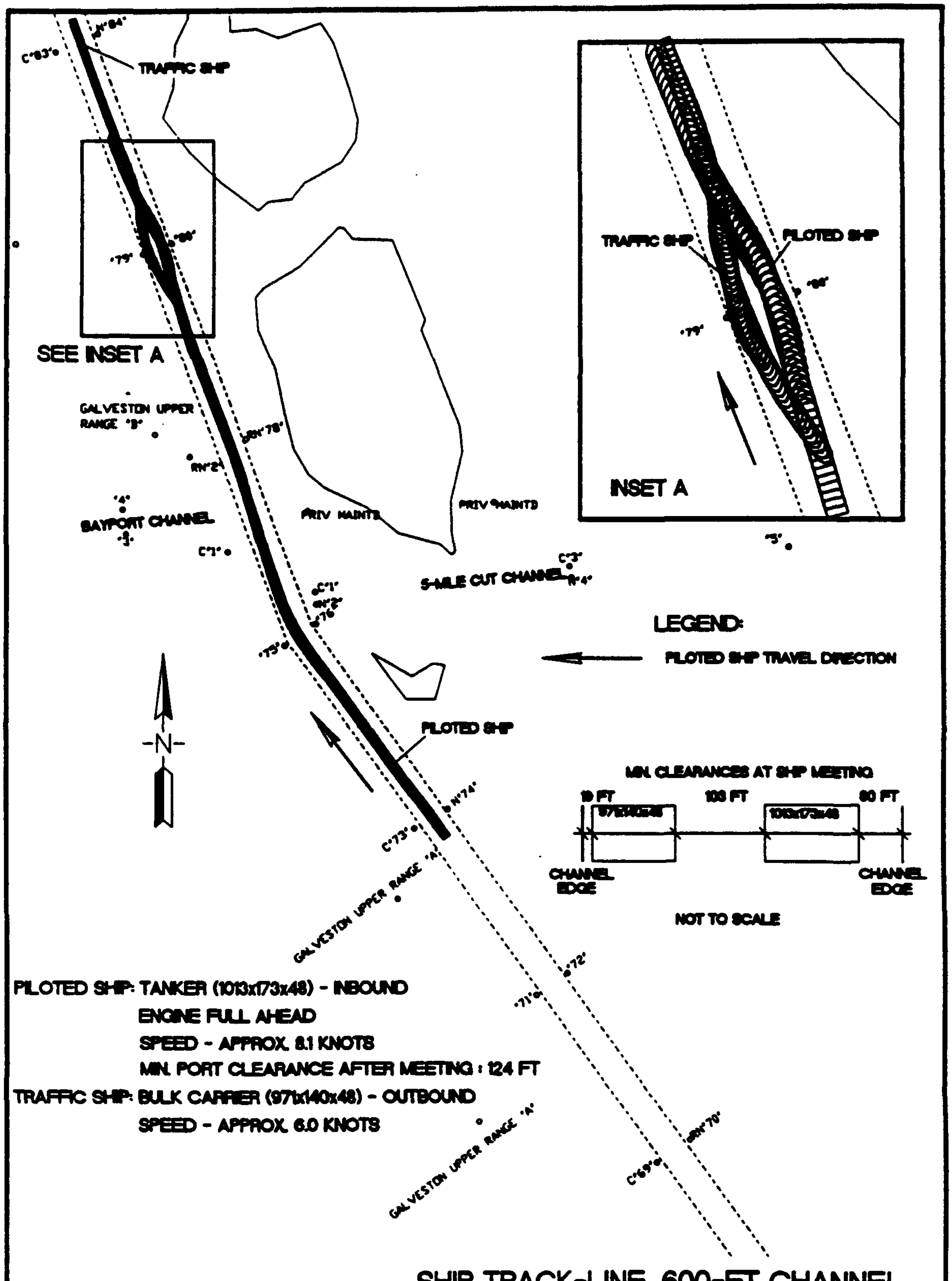
SHIP TRACK-LINE, 600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 1



PILOTED SHIP: TANKER (1013x173x49) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x49) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL

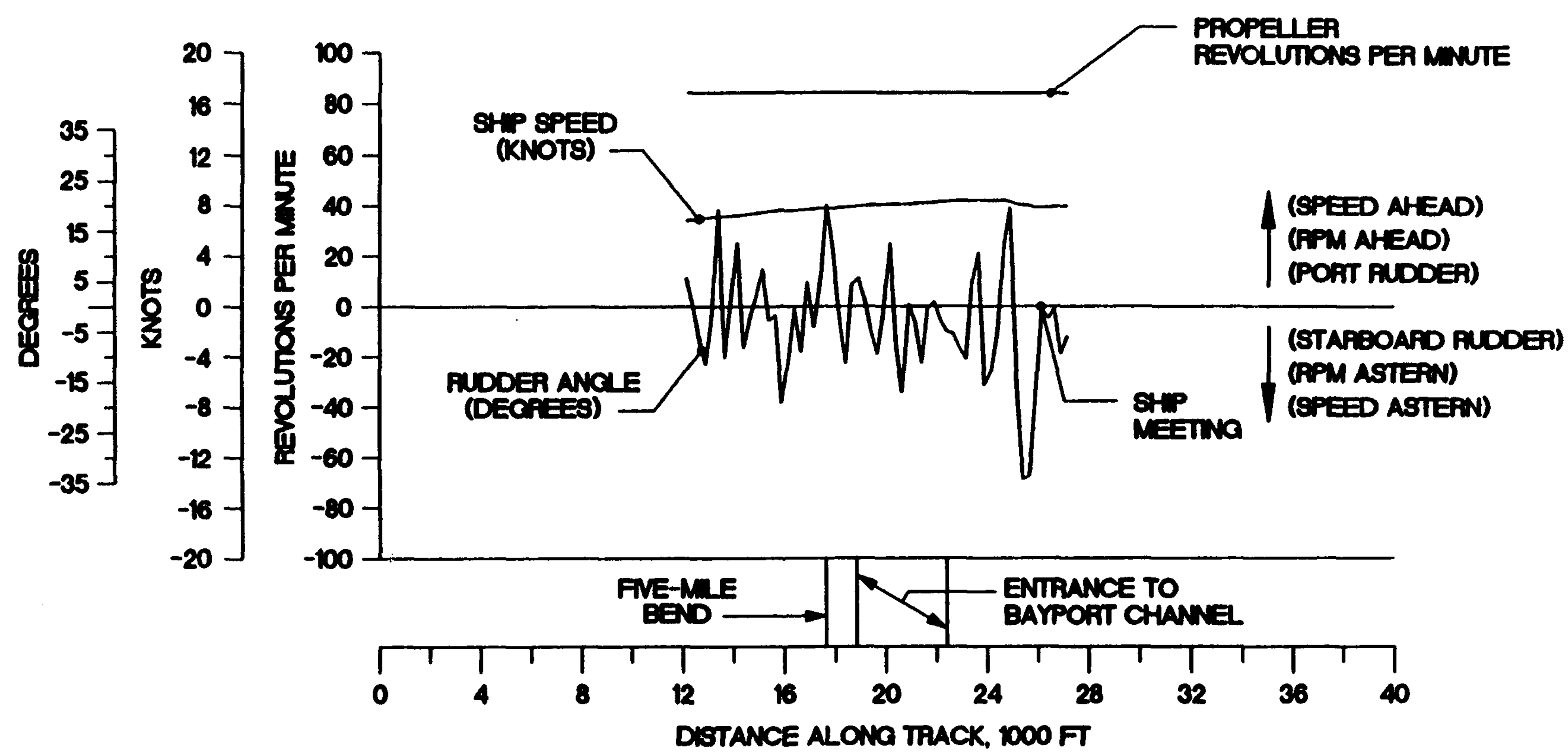
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 1



PILOTED SHIP: TANKER (1013x173x48) - INBOUND
ENGINE FULL AHEAD
SPEED - APPROX. 8.1 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : 124 FT

TRAFFIC SHIP: BULK CARRIER (971x140x48) - OUTBOUND
SPEED - APPROX. 6.0 KNOTS

SHIP TRACK-LINE, 600-FT CHANNEL
BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 2

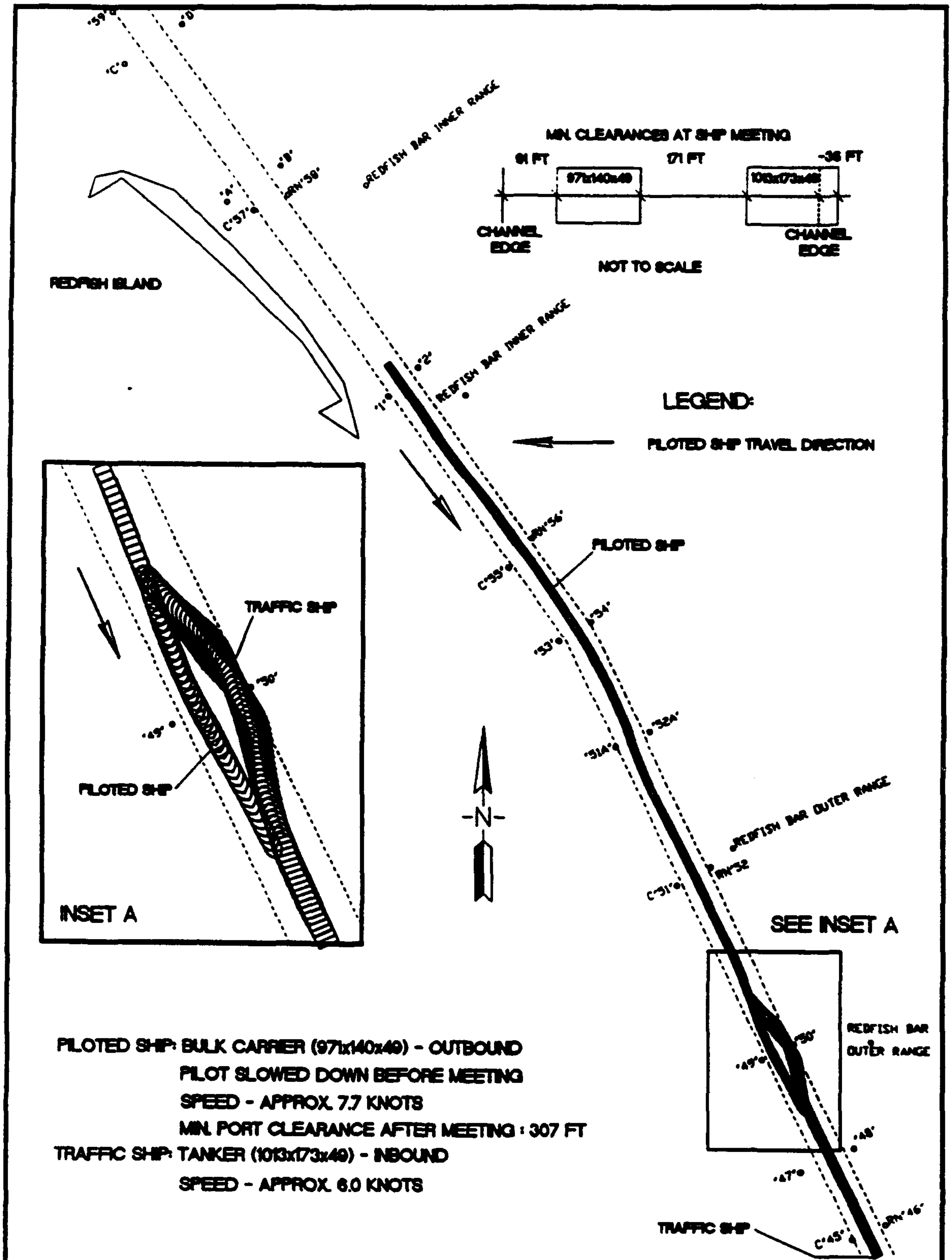


PILOTED SHIP: TANKER (1013x173x48) - INBOUND
TRAFFIC SHIP: BULK CARRIER (971x140x48) - OUTBOUND

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL

BAYPORT VICINITY
FLOOD TIDE, PILOT I, RUN 2

PLATE 100



PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
PILOT SLOWED DOWN BEFORE MEETING
SPEED - APPROX. 7.7 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : 307 FT
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND
SPEED - APPROX. 6.0 KNOTS

SHIP TRACK-LINE, 600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 1

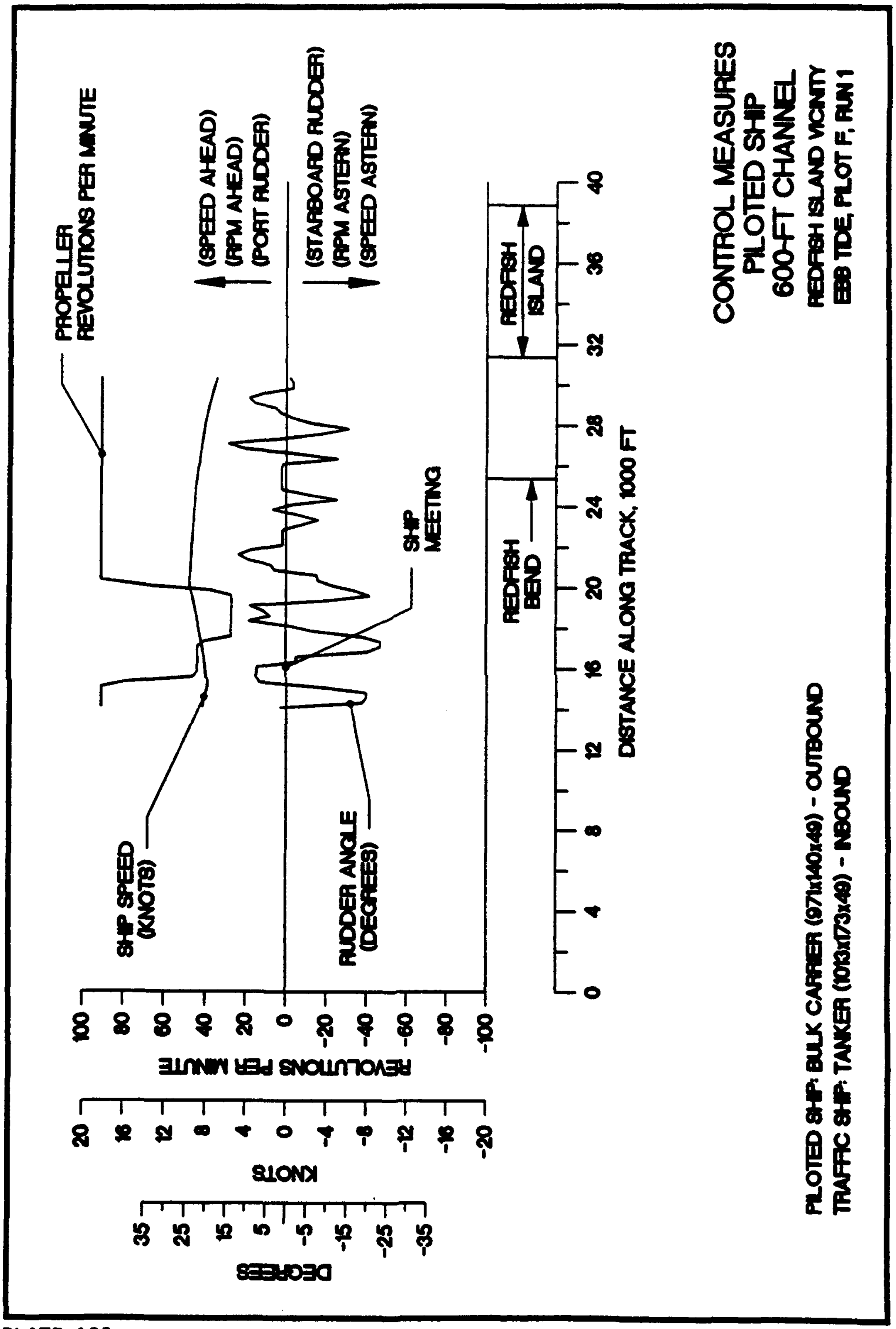
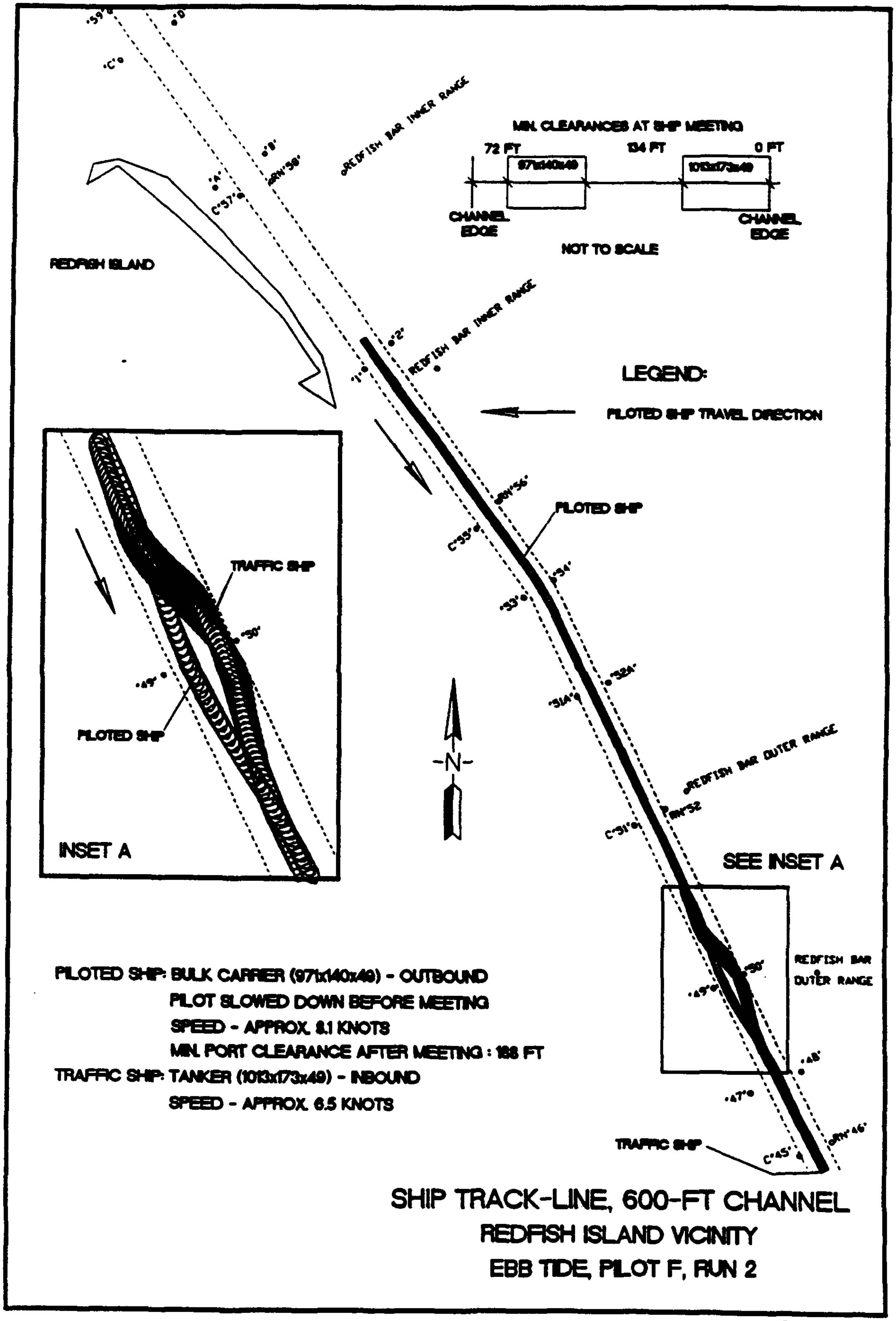
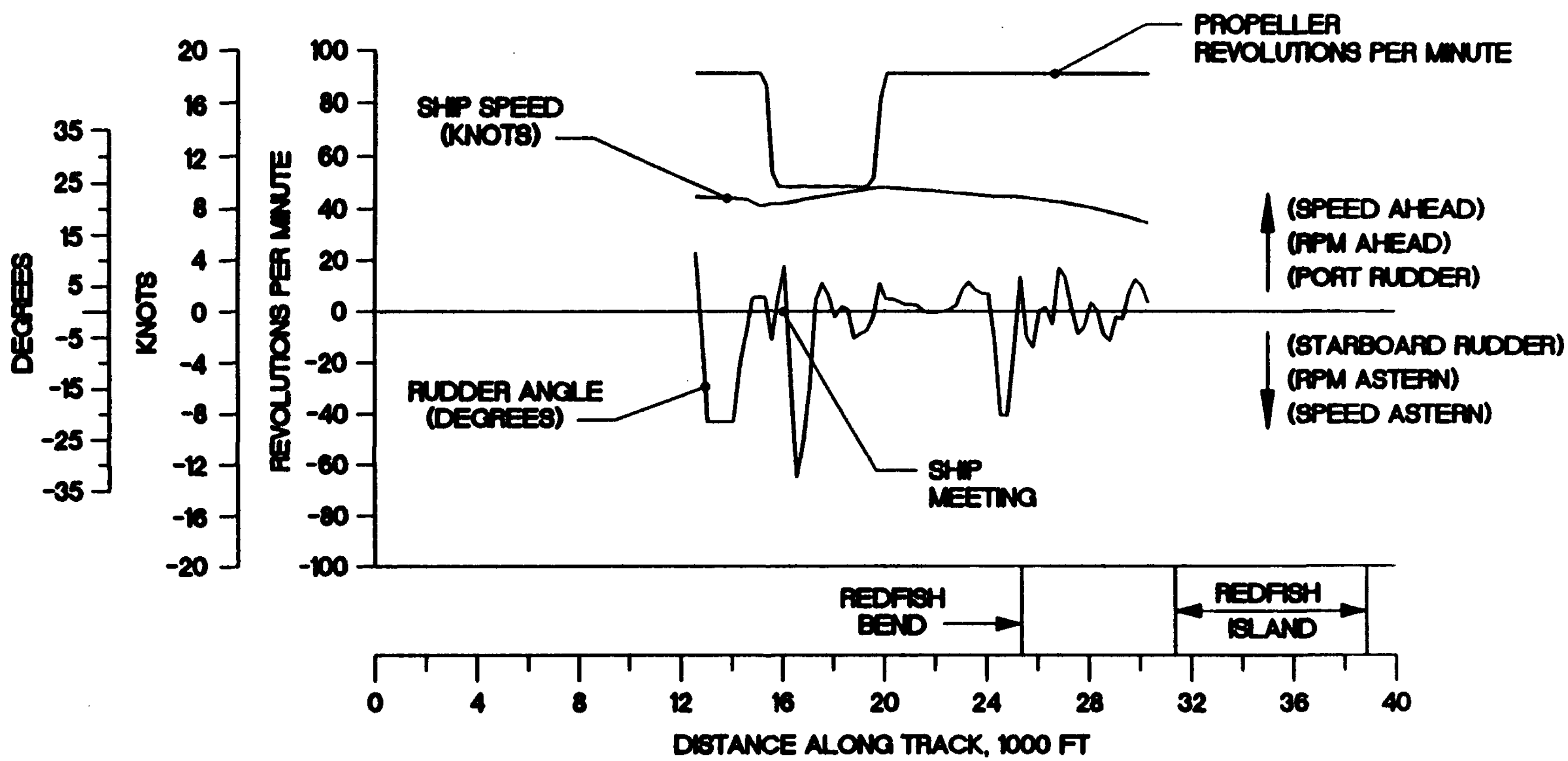

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 1
PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND
PROPELLER REVOLUTIONS PER MINUTE
SHIP SPEED (KNOTS)
RUDDER ANGLE (DEGREES)
SHIP MEETING
(SPEED AHEAD)
(RPM AHEAD)
(PORT RUDDER)
(STARBOARD RUDDER)
(RPM ASTERN)
(SPEED ASTERN)
REDFISH BEND
REDFISH ISLAND
DISTANCE ALONG TRACK, 1000 FT
0
4
8
12
16
20
24
28
32
36
40
REVOLUTIONS PER MINUTE
100
80
60
40
20
0
-20
-40
-60
-80
-100
KNOTS
20
16
12
8
4
0
-4
-8
-12
-16
-20
DEGREES
35
25
15
5
-5
-15
-25
-35

PLATE 102

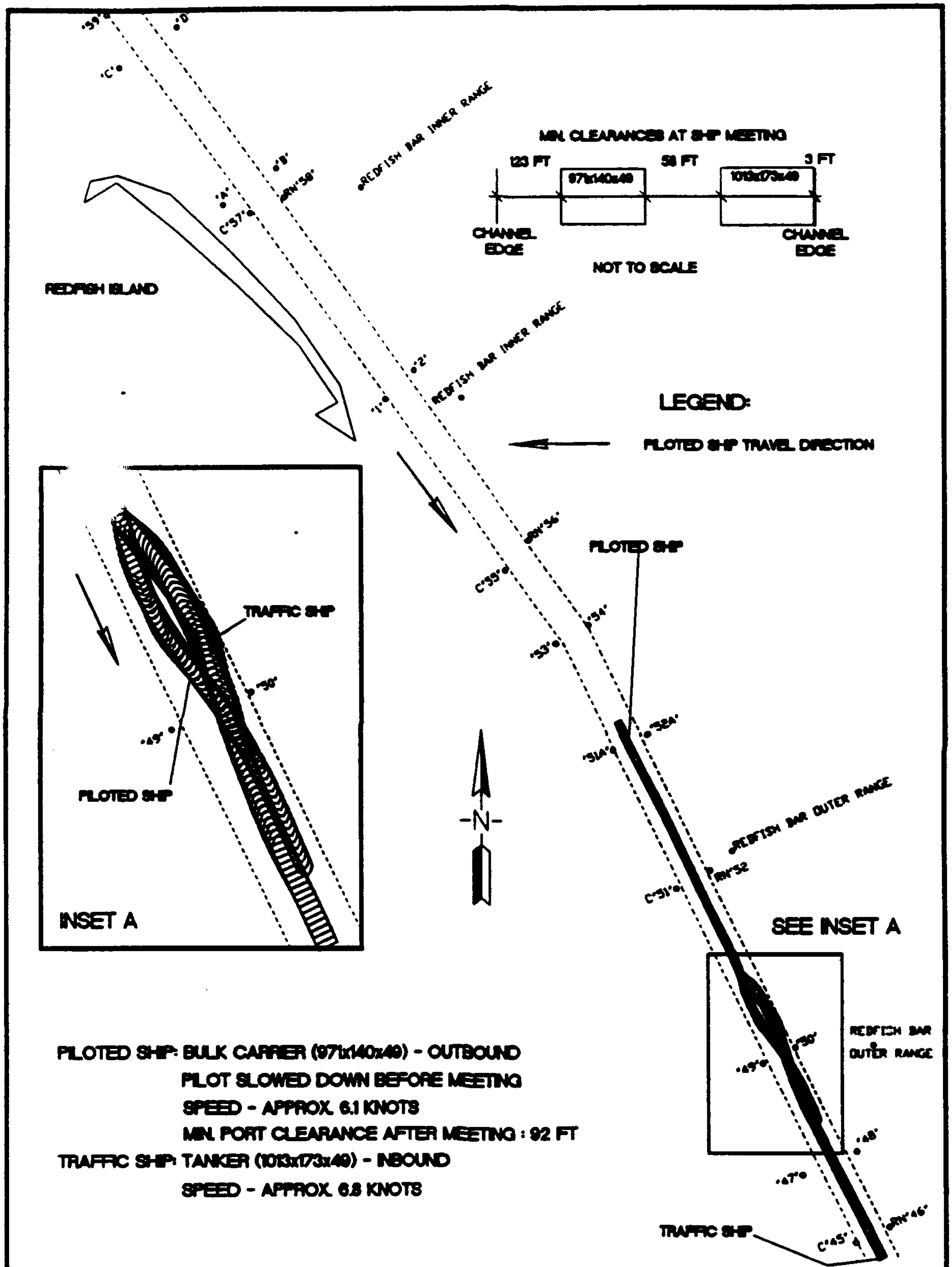


SHIP TRACK-LINE, 600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 2

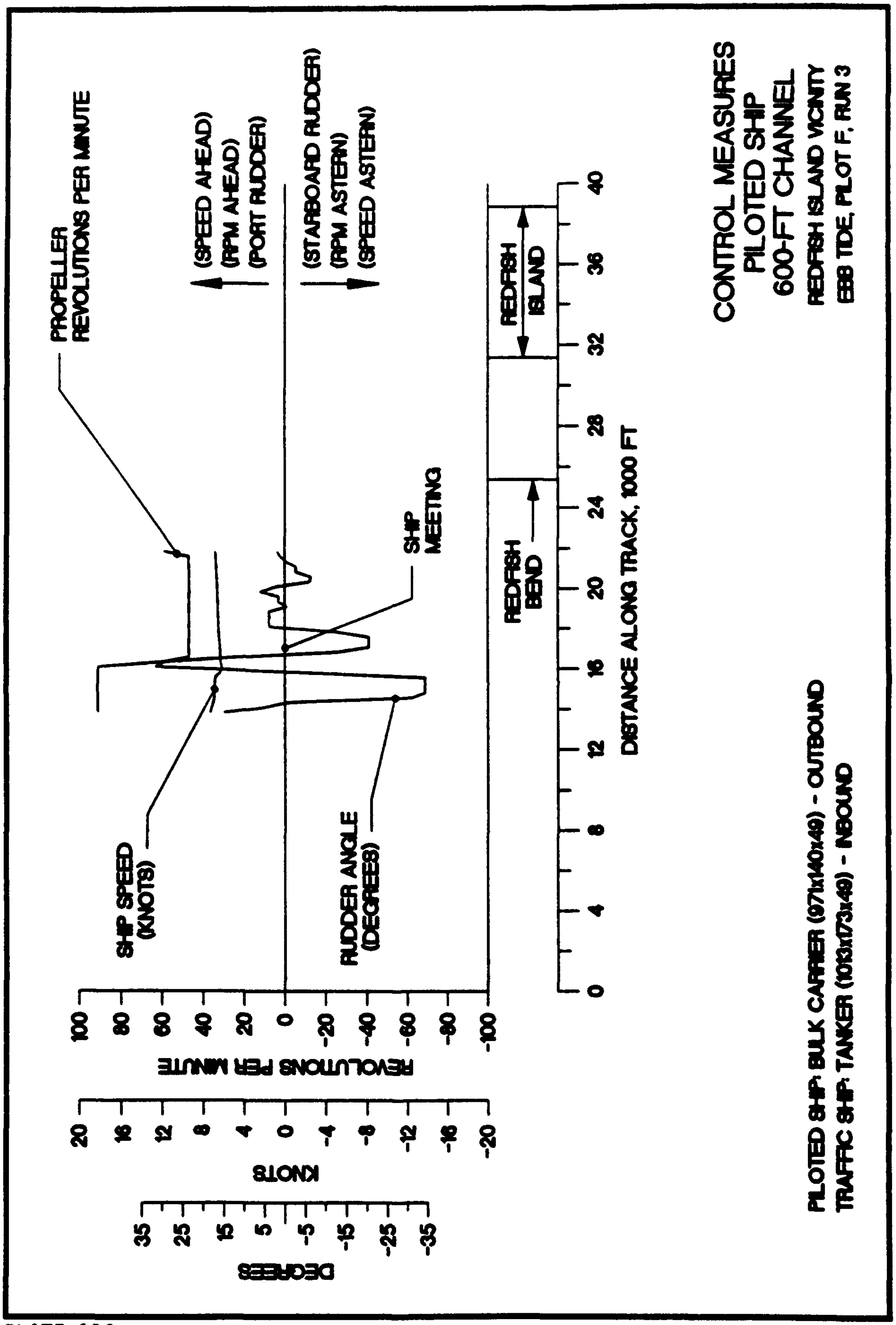


PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 2

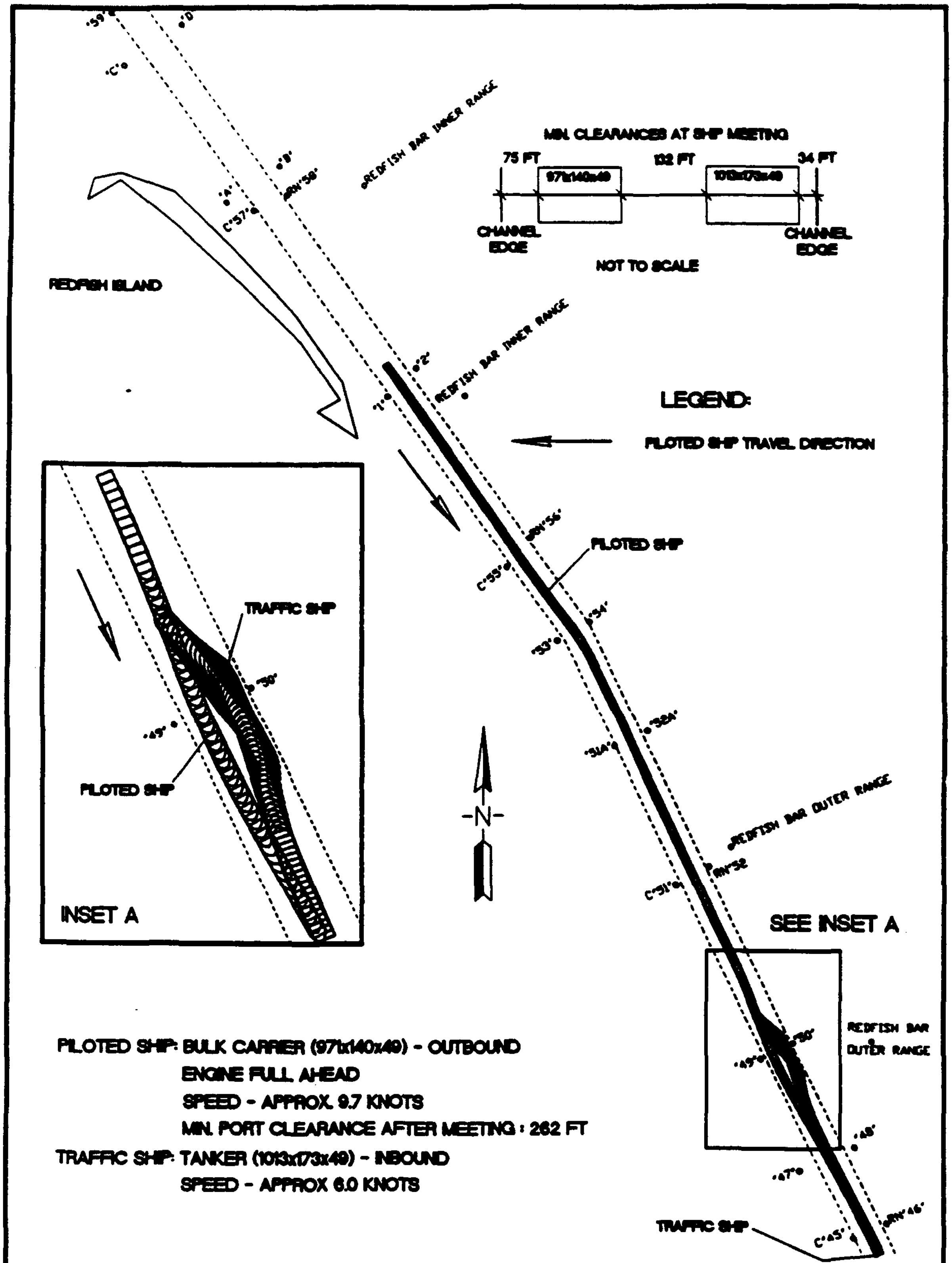


SHIP TRACK-LINE, 600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 3

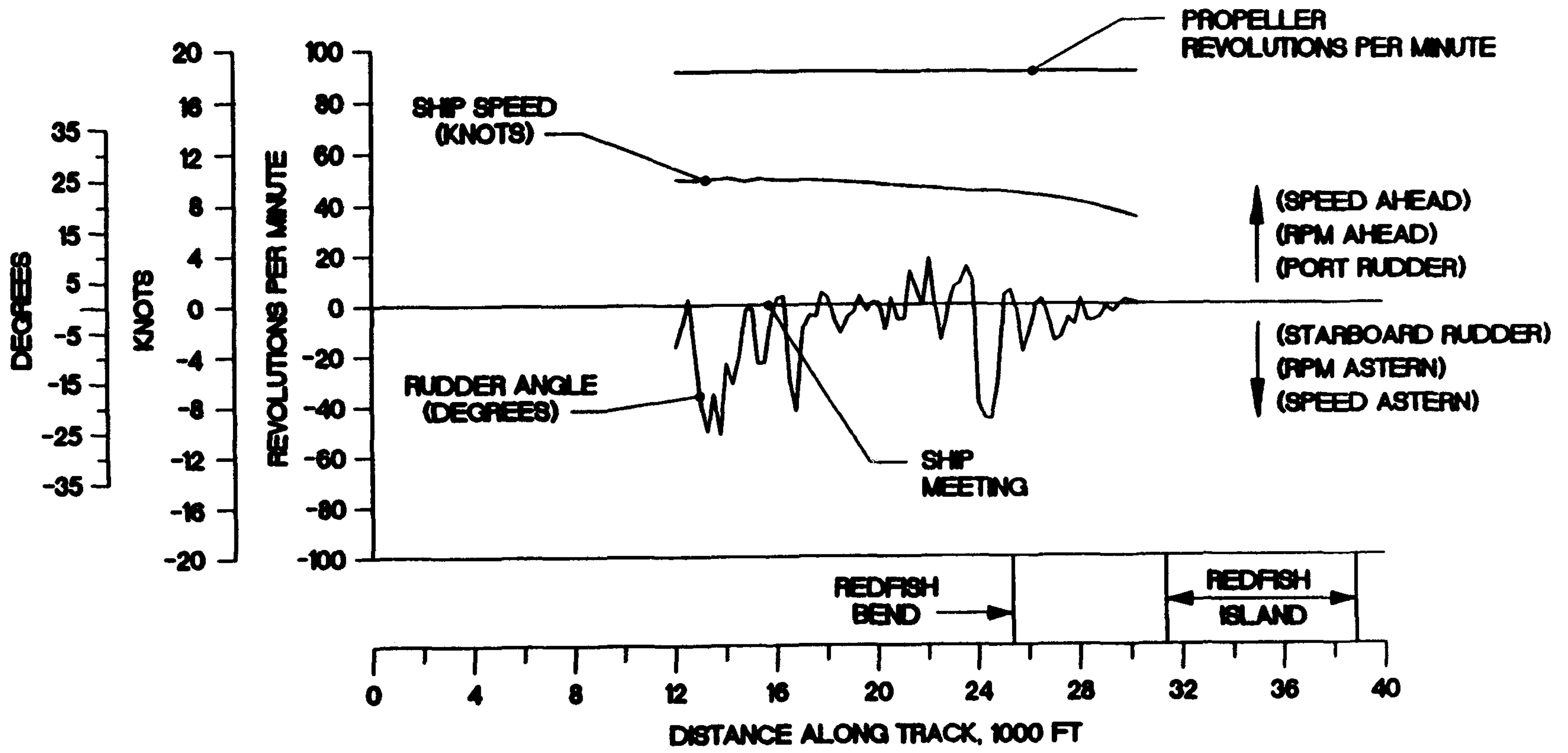


CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT F, RUN 3
PROPELLER REVOLUTIONS PER MINUTE
SHIP SPEED (KNOTS)
RUDDER ANGLE (DEGREES)
SHIP MEETING
(SPEED AHEAD)
(RPM AHEAD)
(PORT RUDDER)
(STARBOARD RUDDER)
(RPM ASTERN)
(SPEED ASTERN)
REDFISH BEND
REDFISH ISLAND
DISTANCE ALONG TRACK, 1000 FT
0
4
8
12
16
20
24
28
32
36
40
REVOLUTIONS PER MINUTE
100
80
60
40
20
0
-20
-40
-60
-80
-100
KNOTS
20
16
12
8
4
0
-4
-8
-12
-16
-20
DEGREES
35
25
15
5
-5
-15
-25
-35
PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND

PLATE 106

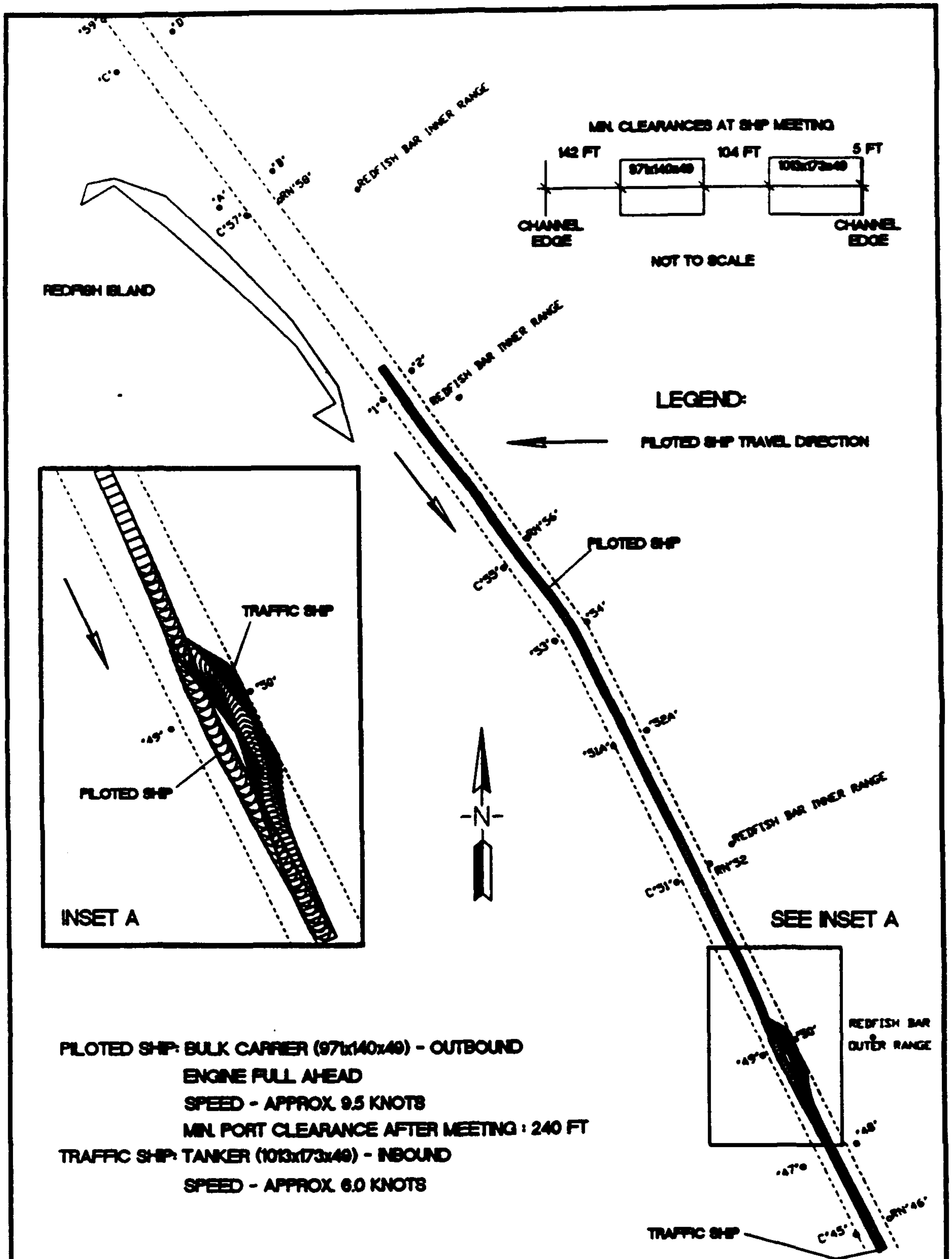


SHIP TRACK-LINE, 600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT G

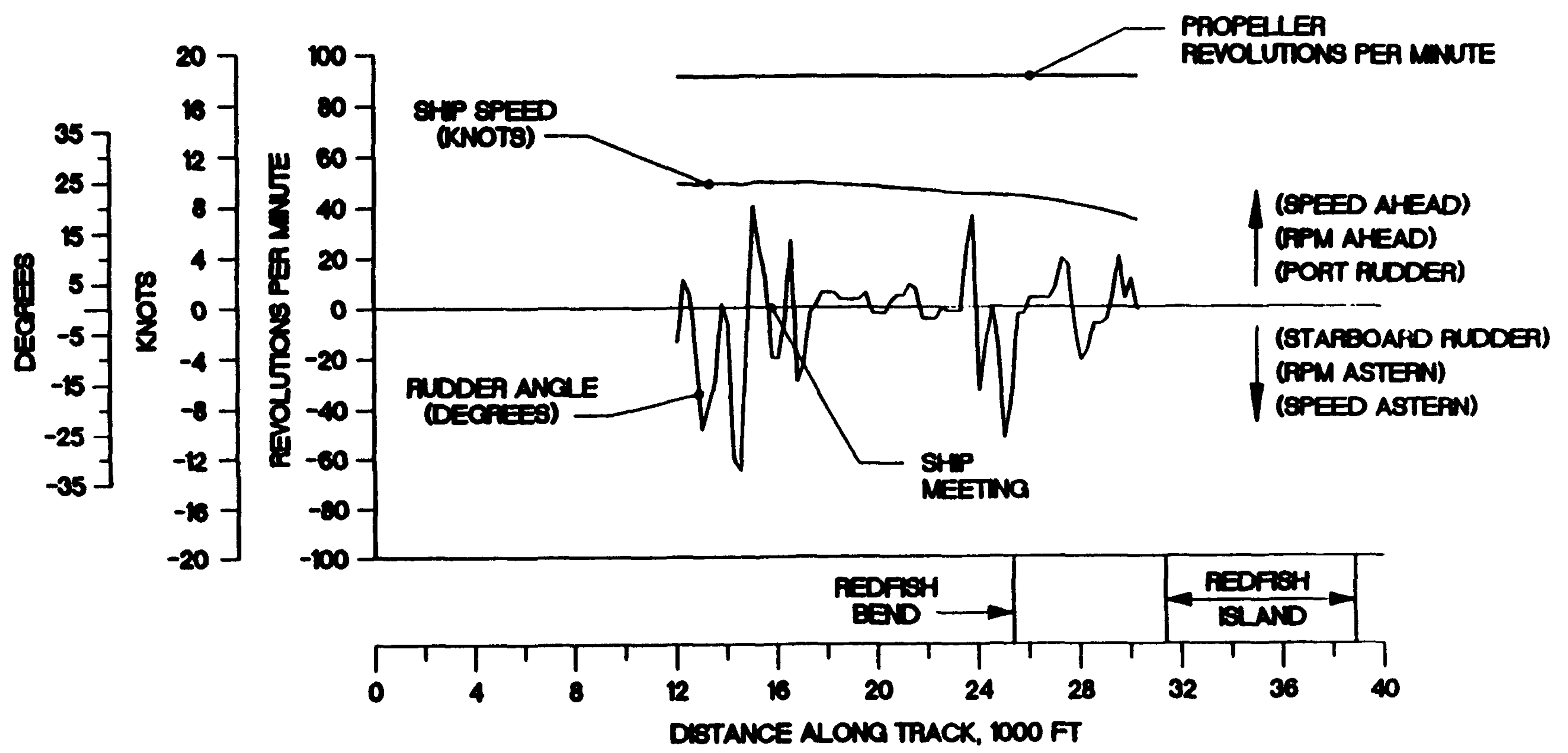


PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT G



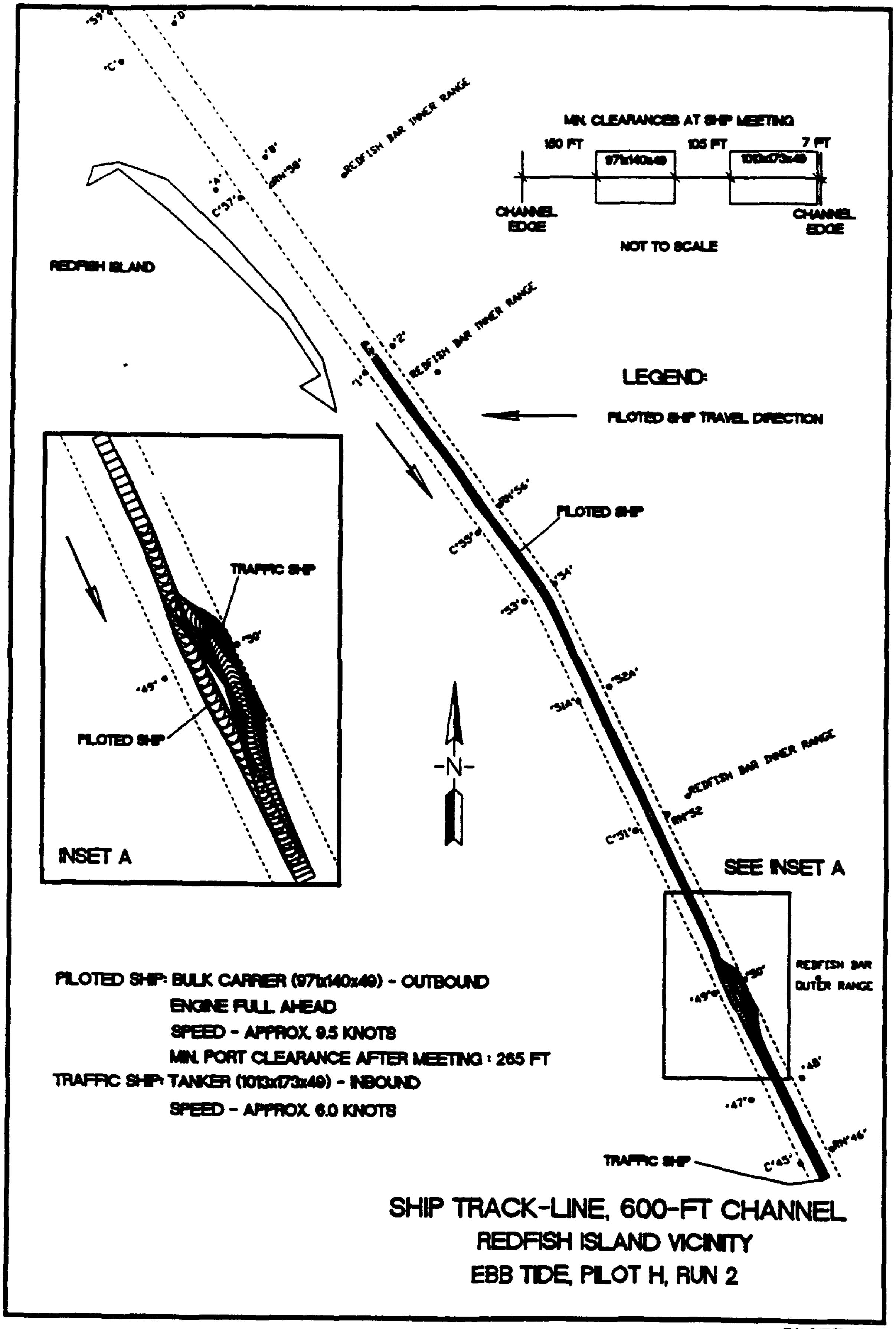
SHIP TRACK-LINE, 600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H, RUN 1

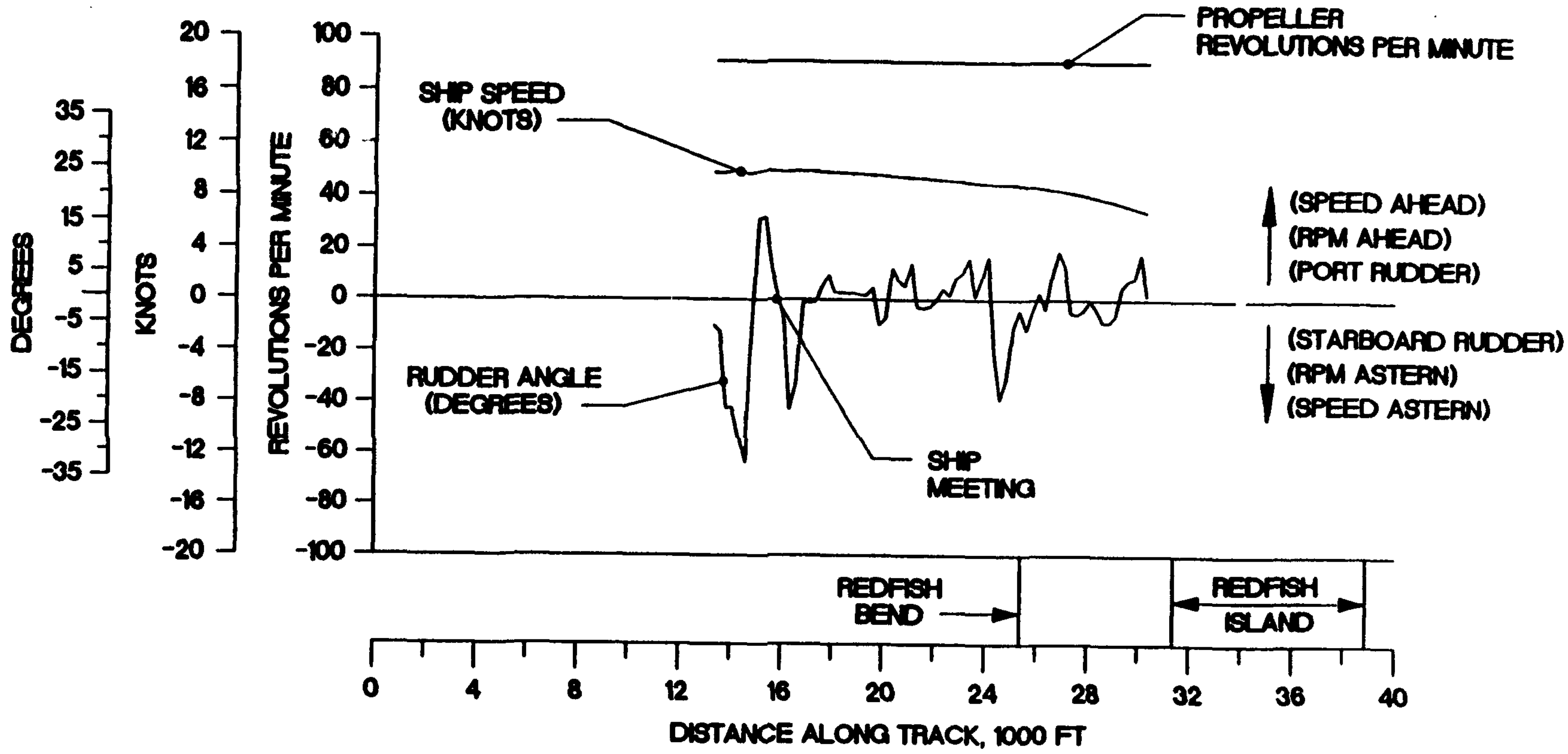


PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H, RUN 1

PLATE 110

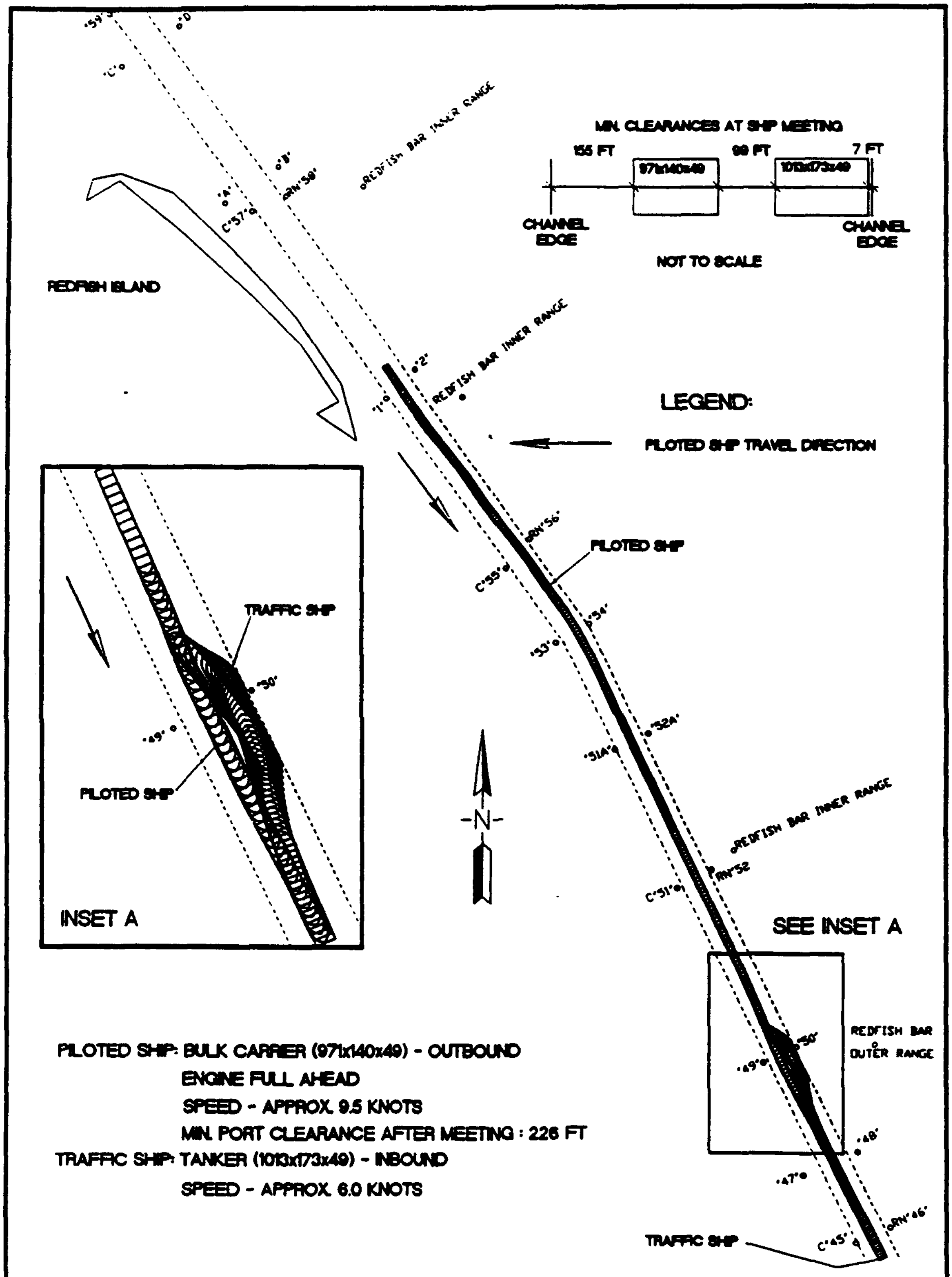

MIN. CLEARANCES AT SHIP MEETING
180 FT
105 FT
7 FT
971x140x49
1013x173x49
CHANNEL EDGE
CHANNEL EDGE
NOT TO SCALE
REDFISH ISLAND
REDFISH BAR INNER RANGE
REDFISH BAR INNER RANGE
REDFISH BAR INNER RANGE
LEGEND:
PILOTED SHIP TRAVEL DIRECTION
PILOTED SHIP
TRAFFIC SHIP
PILOTED SHIP
INSET A
SEE INSET A
REDFISH BAR OUTER RANGE
N
PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
ENGINE FULL AHEAD
SPEED - APPROX. 9.5 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : 265 FT
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND
SPEED - APPROX. 6.0 KNOTS
TRAFFIC SHIP
SHIP TRACK-LINE, 600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H, RUN 2



PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT H, RUN 2

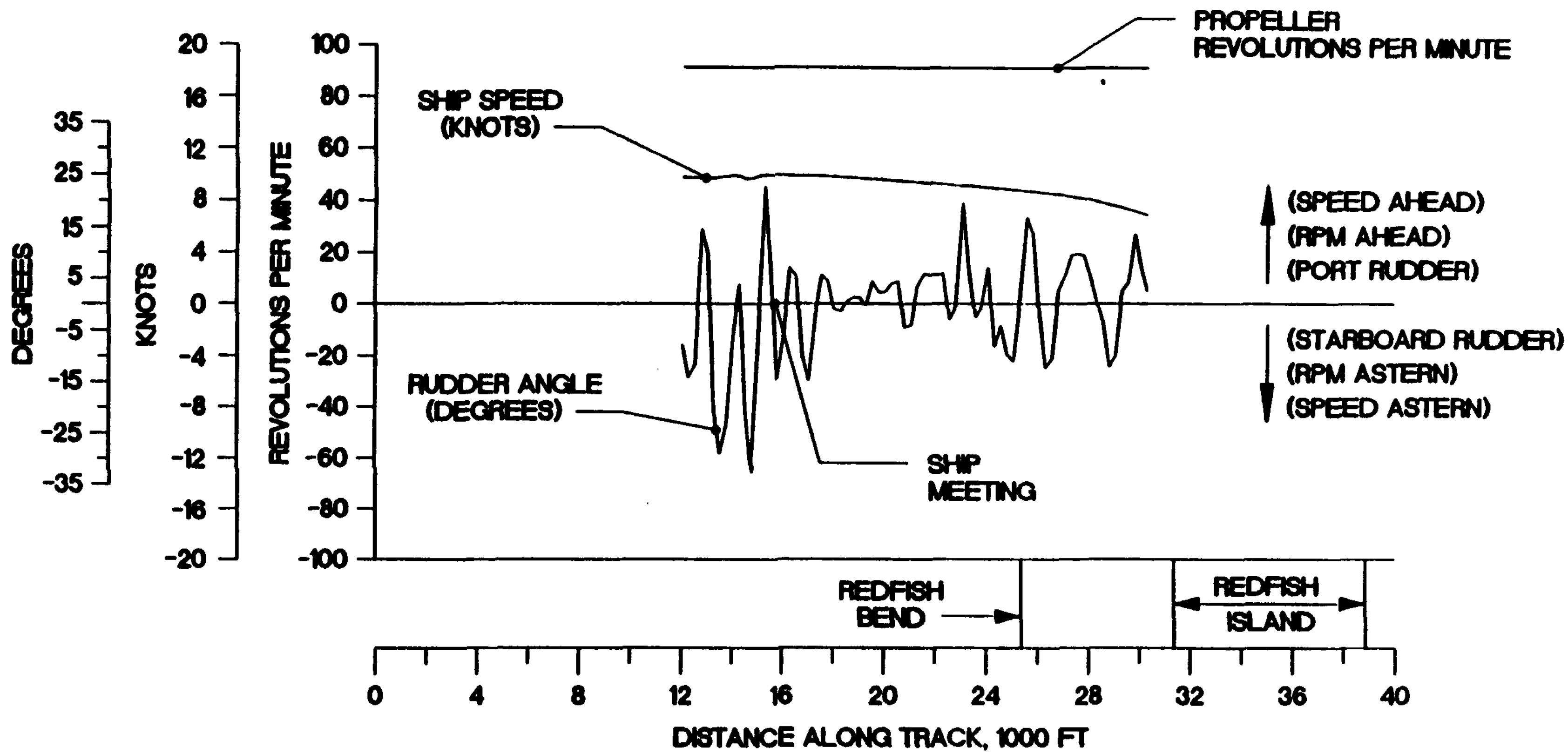
PLATE 112



PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
ENGINE FULL AHEAD
SPEED - APPROX. 9.5 KNOTS
MIN. PORT CLEARANCE AFTER MEETING : 226 FT
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND
SPEED - APPROX. 6.0 KNOTS

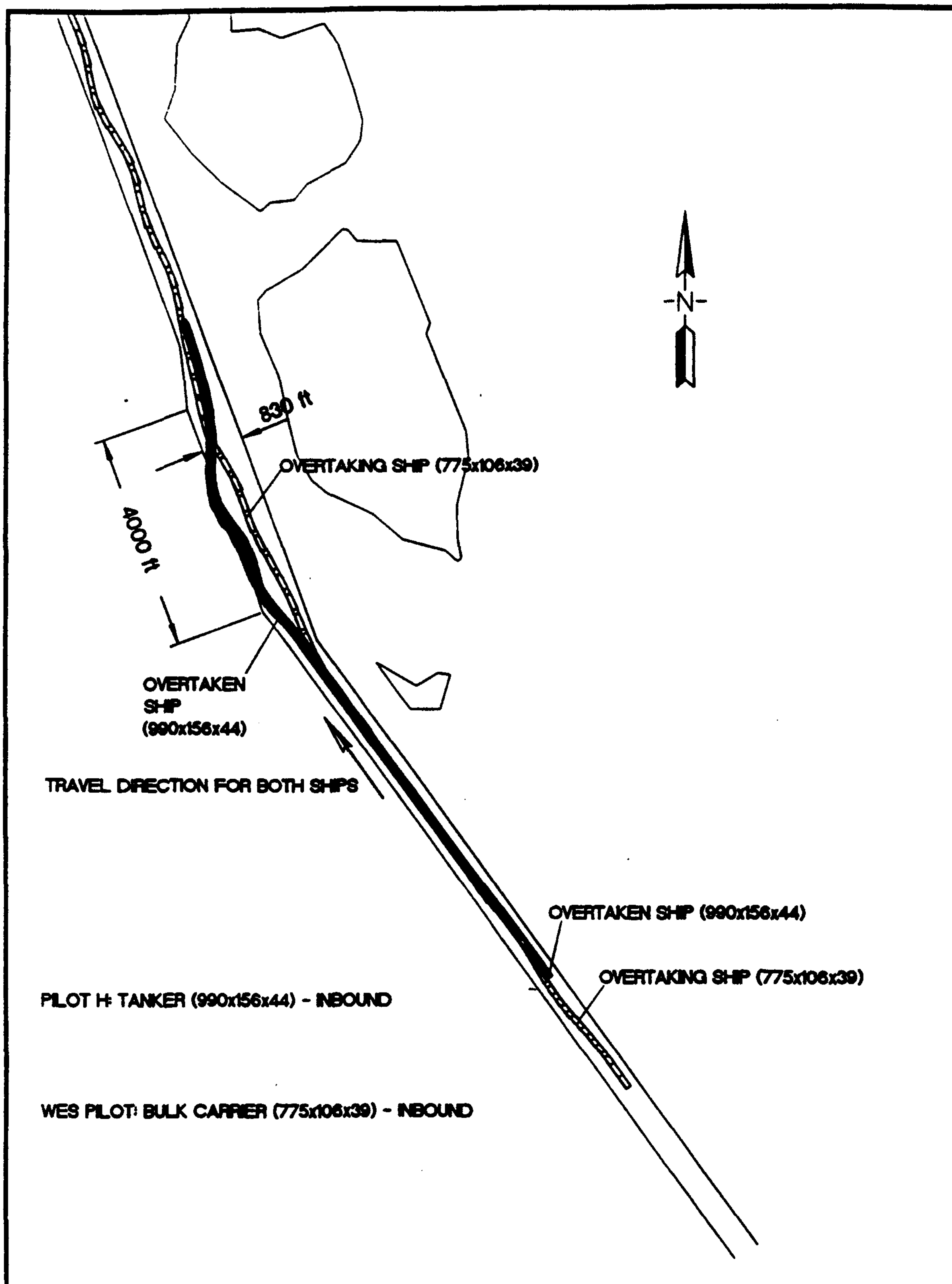
SHIP TRACK-LINE, 600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT I

PLATE 113



PILOTED SHIP: BULK CARRIER (971x140x49) - OUTBOUND
TRAFFIC SHIP: TANKER (1013x173x49) - INBOUND

CONTROL MEASURES
PILOTED SHIP
600-FT CHANNEL
REDFISH ISLAND VICINITY
EBB TIDE, PILOT I



SHIP TRACK-LINE, 530-FT CHANNEL
BAYPORT VICINITY HOLDING AREA
FLOOD TIDE, PILOT H AND WES PILOT

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13. ABSTRACT *(Maximum 200 words)*

A ship computer simulation study for Houston-Galveston Navigation Channels, TX, is performed. The study includes existing conditions and two proposed channel widths. The primary design question is related to ships meeting and passing in the narrow channels. Recommendations are made concerning channel width.

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Ships meeting and passing

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